# Behaviors of Circumferential Through-wall Crack in SA508 Gr.1a LAS and SA312 TP316 SS Pipes under Large Cyclic Loads

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## 1. Introduction

The structural Integrity of system, structure, and components (SSCs) of nuclear power plants (NPPs) in the event of an earthquake is a key issue of design. Thus, the integrity evaluation procedure for earthquake events has been established and applied to the design of NPPs [1]. For instance, the reversible stress cycles corresponding to either at least two safe shutdown earthquake (SSE) events or one SSE and five operating basis earthquake (OBE) events are taken into account for fatigue design of NPPs [2]. However, although crack behaviors are largely affected by cyclic loading, the cyclic loading characteristics of seismic load are not considered in the crack assessment of SSCs [3]. A number of studies have been conducted to evaluate the effect of cyclic load on failure behavior of cracked components and to develop an assessment procedure [4-6]. Despite of these efforts, the effects of cyclic loading on the crack behavior are still uncertain for different materials and loading patterns. In particular, the crack behavior is not clearly understood under a large amplitude cyclic load corresponding to excessive seismic load beyond the design basis.

Therefore, this study conducts fracture tests on the through-wall cracked small-scale pipe specimens under monotonic load and cyclic loads at room temperature (RT). Based on the test results, the effects of cyclic load on the crack behavior are investigated for different piping materials and loading patterns.

## 2. Experiment

Two types of piping materials were used in this experiment: SA508 Gr.1a low-alloy steel (LAS) and SA312 TP316 stainless steel (SS). SA508 Gr.1a LAS is a material used for main piping of reactor coolant system (RCS) and SA312 TP316 SS is commonly used for branch pipes of RCS. Table 1 summaries the mechanical properties of both pipe materials tested at RT. As shown in Fig. 1, small-scale pipe specimen was used for all tests. The dimensions of pipe specimen are 72.5mm in outer diameter, 8.5mm in thickness, and 250mm in length. All specimens had a circumferential through-wall crack with a crack angle of 90°, including a fatigue pre-crack of approximately 10° at each notch tip.

Table 1 Mechanical properties of piping materials used for the experiment

| Materials | Yield stress [MPa] | Tensile stress [MPa] | Uniform elong. [%] | Total elong. [%] |
|---|---|---|---|---|
| SA508 Gr.1a LAS | 338.3 | 516.4 | 17.1 | 32.3 |
| SA312 TP316 SS | 265.9 | 615.8 | 49.9 | 68.3 |

All the tests have been conducted in 4-point bending load without internal pressure at quasi-static displacement rate. Small-scale pipe specimen is too short to apply bending load, so both ends of specimen are connected to the loading bar. The inner and outer spans of 4-point bending are 430mm and 1,630mm, respectively. Regardless of pipe material, the tests have been conducted under monotonic load and displacement- and load-controlled cyclic loads. In the monotonic test, the specimen was periodically unloaded to obtain the specimen compliance. In the displacement-controlled cyclic tests, the displacement was controlled when the specimen was loaded in the crack opening direction and the load was controlled in the compressive loading step with the load ratio (R) of -1.0. The increment of displacement for each step was 0.6mm. The load-controlled tests were conducted under cyclic load of uniform load amplitude with R=-0.5 and R=-1.0, and the maximum of cyclic loads ($P_{max}$) were 75% and 85% of monotonic instability load ($P_{mono}$) for each pipe material. The cyclic load was applied until an unstable propagation occurred in

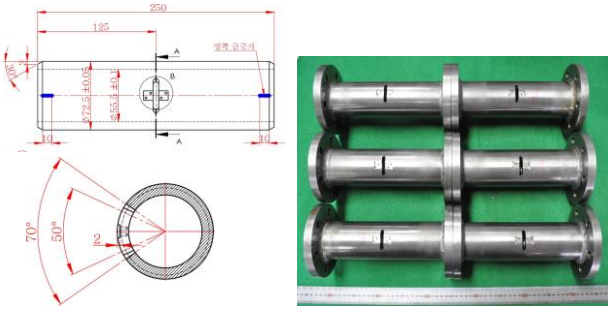


Fig. 1 Small-scale pipe specimen used for the experiment

the through-wall crack.

## 3. Results and Discussion

Under monotonic loads, SA508 Gr.1a LAS pipe specimen showed relatively higher load-carrying capacity, lower deformation ability, and higher crack propagation rate than SA312 TP316 SS pipe specimen. This behavior is related to the high strength and low fracture toughness of SA508 Gr.1a LAS compared to SA312 TP316 SS.

Compared to the monotonic load, the displacement-controlled cyclic load considerably reduced the deformation ability and promoted the crack propagation, and it also reduced the load-carrying capacity of the cracked pipe regardless of material type. However, the reduction of load-carrying capacity was insignificant. The comparison of the results of both pipe materials showed that the reduction in load-carrying capacity and deformation ability by displacement-controlled cyclic load was more significant for SA312 TP316 SS than SA508 Gr.1a LAS. Under displacement-controlled cyclic load, thus, the load-carrying capacity of SA508 Gr.1a LAS pipe was still higher than that of SA312 TP316 SS pipe, but the deformation ability and crack propagation rate for both pipe materials were almost identical. This indicates that the effect of piping material on crack behavior becomes insignificant when cyclic loads are applied to the piping components.

Under the load-controlled cyclic loads, as the load amplitude increased and the load ratio decreased, the failure cycle significantly decreased and the crack length and crack mouth opening displacement at instant of unstable fracture decreased regardless of pipe material. Also, when applying load-controlled cyclic load with lower amplitude and higher load ratio, the ratchet deformation of cracked pipe was significant. Under the same load-controlled cyclic loading condition, the unstable failure of SA508 Gr.1a LAS pipe occurred at higher cycles than that of SA312 TP316 SS pipe. This means that even though the SA508 Gr.1a LAS shows a lower fracture resistance than SA312 TP316 SS under monotonic load, it shows a higher fracture resistance than the SA312 TP316 SS pipe under load-controlled cyclic load. This behavior of cracked pipe would be related to the higher load-carrying capacity of SA508 Gr.1a LAS.

## 4. Conclusions

This study conducted fracture tests using small-scale pipe specimen with a through-wall crack under monotonic load and displacement- and load-controlled cyclic loads at room temperature (RT). The effects of cyclic load on the crack behavior were investigated from the results of tests for different piping materials and loading patterns.

## Acknowledgment

This work was supported by KOREA HYDRO & NUCLEAR POWER CO., LTD. (No. 2017-13)

## References

[1] ASME, *Rules for Construction of Nuclear Facility Components*, ASME B&PV Code, Sect. III, (2007).

[2] USNRC, *SRP 3.7.3 Seismic Subsystem Analysis Review Responsibility*, NUREG-0800, Rev.4, (2013)

[3] ASME, *Rules for Inservice Inspection of Nuclear Power Plant Components*, ASME B&PV Code Sec. XI, (1998).

[4] USNRC, The effect of cyclic and dynamic loading on the fracture resistance of nuclear piping steels, NUREG/CR–6440, (1996).

[5] Y. Yamaguchi, J. Katsuyama, Y. Li, and K. Onizawa, Crack growth evaluation for carbon and stainless steel pipes under large seismic cyclic loading, *Proc. of ASME PVP2015*, Boston, Massachusetts, USA (2015) PVP2015–45834.

[6] J.W. Kim, M.R. Choi, and Y.J. Kim, Effect of loading rate on the fracture behaviour of nuclear piping materials under cyclic loading conditions, *Nuclear Engineering and Technology*, 48 (2016) 1376–1386.