Effect of Stress State and Load Ratio on the Ratchet Deformation of SA508 Gr.1a LAS and SA312 TP316 SS

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1. Introduction

The components and structures of a nuclear power plant (NPP) are designed to have a sufficient safety margin for design basis earthquake (DBE) [1]. However, under beyond design basis earthquake (BDBE), the failure could occur in the area where stress and strain are concentrated, and the failure mode is fatigue cracking or ratchet deformation [2]. In order to reliably assess the seismic safety of structures and components of NPPs under BDBE, thus, it is important to evaluate the low-cycle fatigue damage and ratchet deformation at the strain concentrated areas under large amplitude cyclic loading. In this regard, a number of studies have been conducted to understand the ratcheting behavior of materials and its influencing parameters [2-4]. However, the effect of strain concentration and load ratio on ratcheting behavior is still not clearly understood.

Thus, this study conducted ratchet tests using notched-bar type specimen with two different notch radii under large amplitude load-controlled uniaxial cyclic loads. From the results, the cyclic deformation behaviors were analyzed to investigate the effect of stress state and load ratio on the ratchet deformation of the materials.

2. Experiments

2.1 Materials and Specimen

SA508 Gr.1a low-alloy steel (LAS) and SA312 TP316 stainless steel (SS), which are commonly used as structural materials in NPPs, were used for the experiment. Two types of hourglass-shaped round-bar specimen with a minimum diameter (φ) of 5mm and notch radii of 1.5mm and 6.0mm, respectively, were used (Fig. 1).

2.2 Test Conditions and Procedures

In the tests, we applied load-controlled cyclic load with constant amplitude. As listed in Table 1, three different maximum loads (P_{max}) and three different load ratios were considered for each type of specimen. In Table 1, P_{mono} is the collapse load for each type of specimen under monotonic load. All tests were conducted at room temperature (RT) under a quasi-static rate. A hydraulic dynamic UTM equipped with a 100 kN loadcell was used, and an extensometer with a gauge length of 12.5 mm was used to measure the displacement.

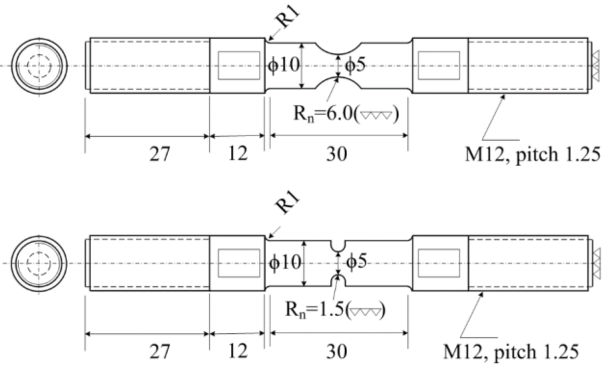

Fig. 1. Specimens used for experiment

3. Results and Conclusions

The load and displacement data were obtained from the tests, and they were normalized with respect to the minimum cross-section of the specimen and gauge length, respectively. The normalized load-displacement curves showed that the width of loop increased with increasing the number of cycles for all test conditions. Also, the specimen failed due to crack initiation on the surface or unstable ductile failure. This indicates that the failure mode of the specimen was found to be ratchet-fatigue or ratchet deformation.

To investigate the ratcheting deformation of specimen, we examined the variation of mean and amplitude of the plastic strain with the number of cycles. Since the normalized displacement is not representative of the strain of the notch cross-section, we calculated the averaged equivalent plastic strain corresponding to the normalized displacement using finite element analysis. Fig. 2 presents variation of the mean and amplitude of the equivalent plastic strain of the SA508 Gr.1a LAS and SA312 TP316 SS specimens under a load with of P_{max} =85%P_{mono} and R=-1.0. Typically, an increase in the mean strain during load-controlled cyclic

Table 1 Test conditions

Material	Temperature [℃]	Notch radius, R_n [mm]	Maximum load, P_{max}/P_{mono} [%]	Load ratio, R
SA508 Gr.1a LAS	RT	1.5	75, 85, 97.5	-1.0, -0.5, 0.0
		6.0	75, 85, 96.7	-1.0, -0.5, 0.0
SA312 TP316 SS	RT	1.5	75, 85, 99.8	-1.0, -0.5, 0.0
		6.0	75, 85, 99.8	-1.0, -0.5, 0.0

loading implies strain accumulation due to ratchet deformation [4].

From the results, it showed that, at a load of R=-1.0, the ratchet deformation was greater with larger notch radii of the specimen for both SA508 Gr.1a LAS and SA312 TP316 SS. However, the effect of the notch radius on the ratchet deformation varied with the load ratio, such that at R=0.0, the ratchet deformation increased with a smaller notch radius. Under the same maximum load condition, the effect of load ratio on ratchet deformation tended to be different for both materials. For the SA508 Gr.1a LAS, the ratcheting rate increased as the load ratio decreased, *i.e.*, the maximum ratchet rate appeared at R=-1.0. For the SA312 TP316 SS, however, the ratcheting rates at R=-0.5 and 0.0 were higher than those at R=-1.0. In most cases, the maximum ratcheting rate was seen at R=-0.5. Also, the ratcheting deformation was greater for SA508 Gr.1a LAS than for SA312 TP316 SS under the same loading condition and specimen geometry. This is related to the different cyclic hardening characteristics of the materials [4]. That is, SA508 Gr.1a LAS exhibits negligible cyclic hardening behavior, whereas SA312 TP316 SS exhibits significant cyclic hardening behavior.

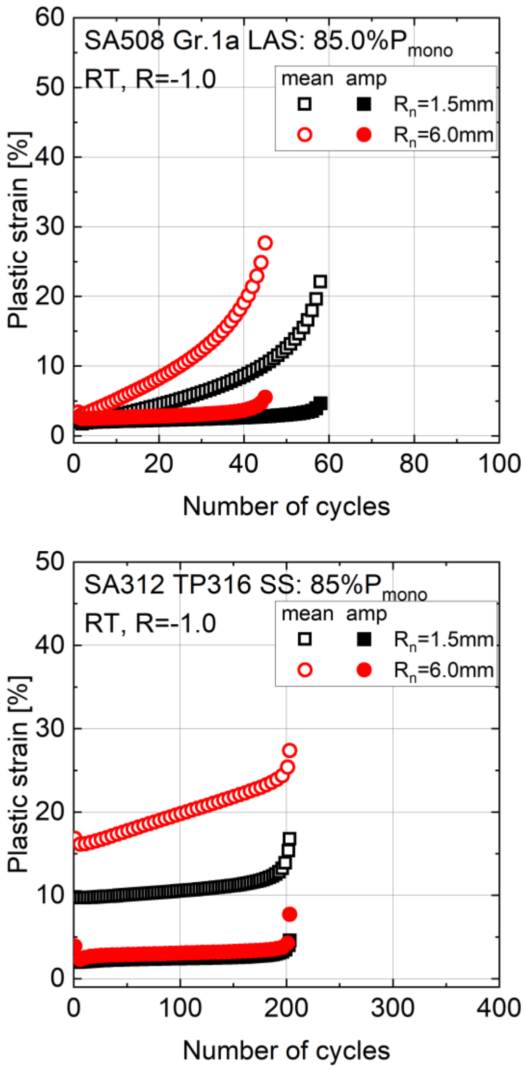

Fig. 2. Variation of mean and amplitude of plastic strain with the number of cycles under a load with a maximum load of 85%P_{mono} and R = -1.0

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REFERENCES

[1] USNSC, Regulatory Guide for Reviewing Seismic Design of Nuclear Power Reactor Facilities, Nuclear Safety Commission., 2006.
[2] A. R. Kiran, G. R. Reddy, P. N. Dubey, and M. K. Agrawal, Fatigue-Ratcheting Behavior of 6 in Pressurized Carbon Steel Piping Systems Under Seismic Load: Experiments and Analysis, Journal of Pressure Vessel Technology, Vol.139, p.061801, 2017.
[3] S. Goyal, S. K. Gupta, V. Bhasin, K. K. Vaze, A. K. Ghosh, S. Vishnuvardhan, M. Saravanan, D. M. Pukazhendhi, P. Gandhi, and G. Raghava, Fatigue Ratcheting Investigation on Pressurized Elbows made of SS304 LN, 15th ICTACEM, pp. 578-580, 2010.
[4] S. K. Paul, A critical review of experimental aspects in ratcheting fatigue: microstructure to specimen to component, Journal of Materials Research and Technology, Vol.8, pp.4894-4914, 2019.