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Cyclic fracture behaviors of TP304 stainless steel base and weld metals under displacement- and load-controlled loads

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1. Introduction

As several nuclear power plants (NPPs) have experienced large earthquakes exceeding design basis, maintaining the structural integrity of safety-related nuclear system, structure, and components (SSCs) under excessive seismic loads has become an important issue [1]. Thus, the rational structural integrity assessment procedures have been developed and applied to seismic margin analysis of SSCs under excessive seismic events. In addition, as cracks have been detected in some SSCs of long-term operated NPPs, it is recently required to assess the structural integrity considering the cracks in SSCs under excessive seismic loads [2]. However, the assessment procedure for cracked SSCs subjected to large amplitude cyclic loads has not been developed yet.

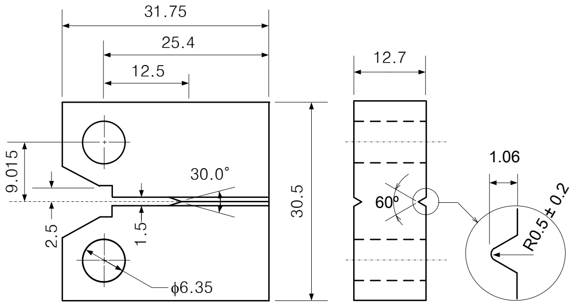
Thus, this study carried out cyclic tearing tests to investigate the effect of large amplitude cyclic loads on the fracture behaviors of cracked SSCs. The tests were conducted on TP304 stainless steel (SS) base and weld metals, which are used as nuclear reactor internal materials, under displacement- and load-controlled cyclic loads at RT and 316ºC. From the results, the effect of cyclic loads on the load carrying capacity, deformation behavior, and number of cycles to instability of the specimens was evaluated for both materials.

2. Experiment

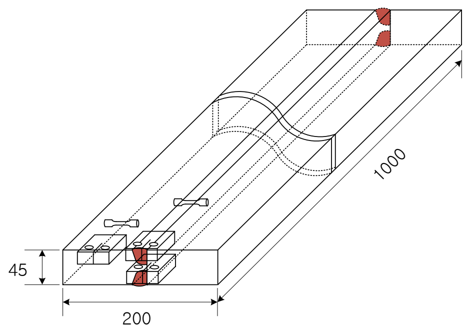
In the tests 0.5T-CT specimen with side-grooves, designed in accordance with ASTM E1820-15 [3], was used as shown in Fig. 1(a). The specimens were machined from SA240 TP304 SS base and weld metals in the T-L direction (Fig. 1(b)). SA240 TP304 SS was provided as a plate with a thickness of 45mm. Weld metal was prepared by K-groove welding of both sides of SA240 TP304 SS plate. Table 1 lists the chemical compositions of SA240 TP304 SS base and weld metals.

In the displacement-controlled cyclic tests, a constant displacement increment was applied for each cycle and the load ratio was kept constant. The displacement was controlled when the tensile loading was applied to the specimen, and load was controlled during the compressive loading. Two different displacement increments (0.15 and 0.25 mm) and load ratio of R=-1.0 were considered in the displacement-controlled cyclic tests. For load-controlled cyclic tests, the specimen was subjected to cyclic loading with constant load amplitude and constant load ratio. The load amplitude and load ratio applied to the tests were $P_a = 70\%P_L, 85\%P_L$ and $R = -0.65,\ -1.0$, respectively. Where P_L is the limit load of 0.5T-CT specimen under plane strain condition [4]. In the load-controlled tests, cyclic load was applied until unstable fracture occurred in the specimen, and the crack length was determined from the elastic slope during unloading.

Fracture test was also conducted to obtain the maximum load of specimen under monotonic load for each material at RT and 316ºC.



(a) 0.5T- CT specimen



(b) Location and direction of specimen

Fig. 1 Dimension and location of 0.5T-CT specimen used for cyclic tearing tests

Table 1 Chemical compositions of as received SA240 TP304 SS and weld metal used for the experiment

Mater.	C	Si	Mn	P	S	Cr	Ni	Mo	N	Co	Cu	F/N No.
SA240 TP304	0.030	0.40	1.56	0.032	0.005	18.15	8.05	0.12	0.070	0.21	0.24	-
Weld metal	0.020	0.40	1.90	0.024	0.010	19.64	10.79	0.03	-	-	0.10	5.8

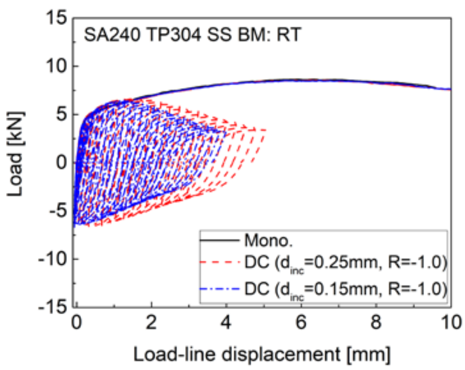


Fig. 2 Load-displacement curves of monotonic and displacement-controlled cyclic loads

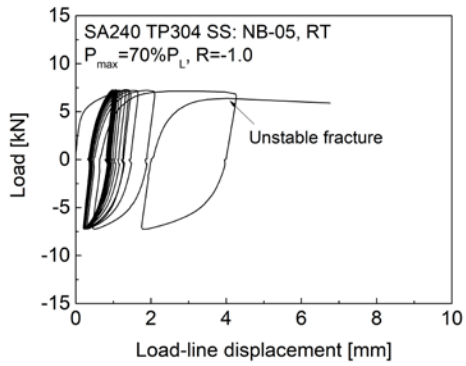
3. Results and Discussion

The results of tests showed that, the maximum load and displacement to maximum load were decreased when applying displacement-controlled cyclic load compared to monotonic load (Fig. 2). In particular, the decrease in the displacement to maximum load was significant. This implies that the displacement-controlled cyclic load slightly reduces the load-carrying capacity of cracked SSCs, but significantly reduces the deformation ability. Such effects were also observed for all test conditions and were consistent with observations from previous studies [5].

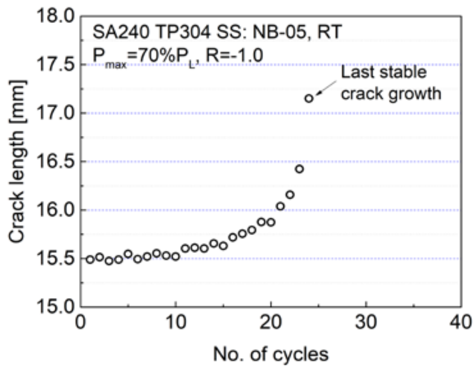
As shown in Fig. 3, as cycles of load-controlled cyclic load increased, the amplitude of load-line displacement (*LLD*) and crack growth increased marginally during initial cycles, and they increased rapidly in later cycles nearing to instability. Also, the results showed that, regardless of test temperature and material, the number of cycles and crack extension to instability decreased with increase in load amplitude at a given load ratio. As the load ratio increased at the same maximum load, the number of cycles and *LLD* to instability considerably increased, but the crack extension to instability was less affected by load ratio. This indicates that the crack extension to instability is mainly governed by the maximum load of the cyclic loads. As the load ratio increased at the same amplitude, the *LLD* of specimens at instant of instability considerably increased for both materials at RT and 316°C. However, the effect of the load ratio on the number of cycles to instability was different in both test materials. With increasing the load ratio, the number of cycles to instability increased for base metal, but decreased for weld metal. This is associated with the difference in yield strength between the base and weld metals of TP304 stainless steel.

4. Conclusions

This study conducted cyclic tearing tests on TP304 SS base and weld metals under displacement- and load-control modes. The effect of cyclic loads on the load carrying capacity, deformation, and number of cycles to instability of specimens was investigated for both materials.



(a) Load-displacement hysteresis



(b) Crack extension

Fig. 3 Sample of data tested under load-controlled cyclic load

Acknowledgment

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