Dynamic Strain Aging Effects on Inelastic Behaviors of Type 316H at Elevated Temperature

Ji-Hyun Yoon[a,b]*, Young-Choon Kim[b], Gyeong-Hoi Koo[a], Bong-Sang Lee[a,b]
[a]*Korea Atomic Energy Research Institute, 150-1 Deogjin-Dong, Yuseong, Daejeon, 305-353, Korea*
[b]*University of Science & Technology, 217Gajeong-ro, Yuseong, Daejeon, 305-333, Korea*
**Corresponding author: jhyoon4@kaeri.re.kr*

1. Introduction

The structural components in sodium-cooled fast reactor (SFR) will be subjected to a harsh operating conditions such as much higher temperature and neutron dose comparing to that of conventional reactors [1, 2]. It is desirable to have a constitutive model which accurately describes the history dependence of long-term mechanical response, e.g. cyclic deformation response in order to improve the reliability of lifetime assessment procedures [3]. Therefore, it is needed to evaluate the inelastic characteristics of RPV materials such as ratcheting that can be induced by cyclic thermal stress resulted from fluctuation of coolant level. The high amount of strain accumulation due to ratcheting in service of SFR can thin down the structural components in the primary sodium circuit subsequently leading to buckling [4].

However, the experimental data which are needed to provide material parameters of inelastic constitutive equation for Type 316H stainless steel which is the prime candidate material for RPV of Korean SFR are very rare.

It is reported that the inelastic behaviors of certain materials could be affected by dynamic strain aging (DSA).

The objectives of this study are to obtain the fully reversed cyclic data and ratcheting data for Type 316H stainless steel and to investigate the effects of DSA on the inelastic behaviors of Type 316H stainless steel.

2. Experimental

The round type specimens for both strain-controlled fully reversed cyclic tests and ratcheting tests were machined out from a Type 316 stainless steel plate with a thickness of 19 mm. The chemical composition of the material is listed in Table 1. The diameter and gage section of the specimens were 6 mm and 12 mm, respectively. The testing were conducted at up to 650°C using a 100 kN-capacity MTS 810 servo-hydraulic test machine equipped with 3 zone electric furnace. The strain rate and amplitude of the testing were 10^{-4}/s and 0.6 %, respectively for the fully reversed cyclic testing. The stress rate, amplitude and mean stress were 5 MPa/s, 150 MPa and 50MPa, respectively.

The tension testing were conducted for Type 316H specimens at a temperature range of 450-550^{o}C and a strain range of 10^{-4}-10^{-2}/s. The tension testing were conducted for Type 316H specimens at a temperature range of 450-550^{o}C and a strain range of 10^{-4}-10^{-2}/s.

The test system used for cyclic and tension testing is shown in Fig. 1.

Table 1. Chemistry of Type 316H stainless steel plate.

Cr	Ni	Mo	Mn	Si	Cu	C	N
16.26	10.16	2.05	1.76	0.44	0.48	0.05	0.05

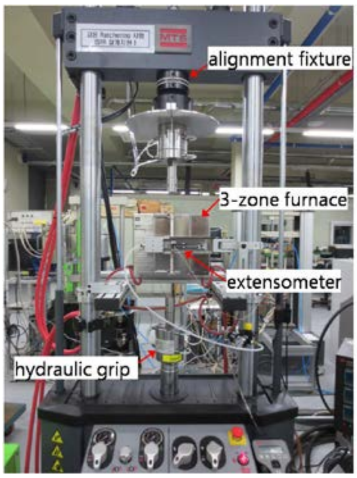

Fig. 1. Cyclic test system equipped with 3 zone furnace and high temperature extensometer.

3. Results and Discussion

It was observed that the stress amplitude increased as the number of cycle increased at all temperatures including room temperature. However, the cyclic number for saturated stress-strain loop was different for each temperature.

By defining the maximum cyclic hardening ratio as the maximum peak stress divided by the initial peak stress, the hardening ratio as a function of temperature was derived in Fig. 4. Fig. 4 indicated that the hardening was strongly pronounced in a temperature range 500-575^{o}C. It was reported that the hardening magnitude of austenitic stainless steel increased in low cycle fatigue test at elevated temperature due to DSA [5] .

Fig. 5 - Fig. 7 show the accumulated ratcheting strain as a function of cycles at room temperature, 550^{o}C and 650^{o}C, respectively.

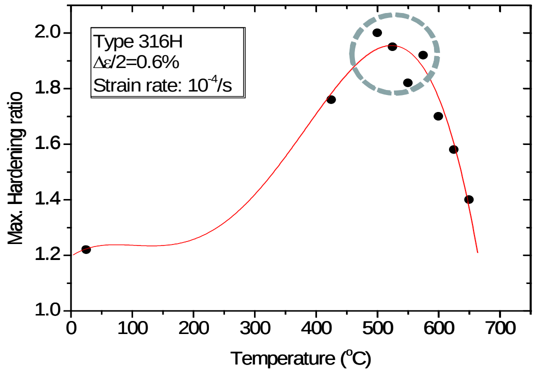

Fig. 4. Maximum cyclic hardening ratio as a function of temperature for Type 316H stainless steel.

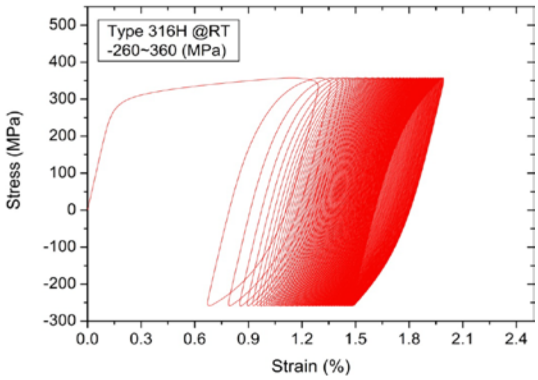

Fig. 5. Ratcheting strain accumulation for Type 316H at room temperature.

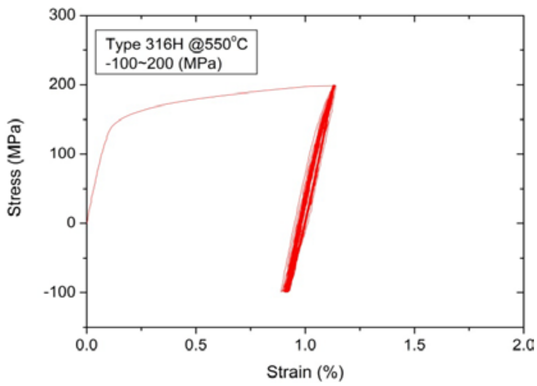

Fig. 6. Ratcheting strain accumulation for Type 316H at 550°C.

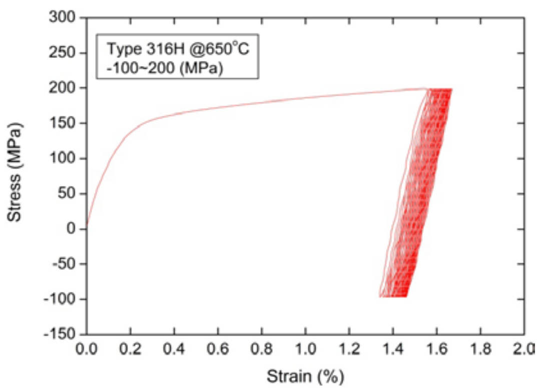

Fig. 7. Ratcheting strain accumulation for Type 316H at 650°C.

It is notable that the ratcheting deformation rate of Type 316H at 550°C was much slower than that at room temperature and it recovered a little bit at 650°C.

The results for tension testing conducted at a temperature range of 450-550°C shows the serrated flows generated in this temperature range. Therefore, it was concluded that the sharp increase in hardening ratio and the retardation of ratcheting strain accumulation in Type 316H stainless steel at 500-575°C was attributed to DSA.

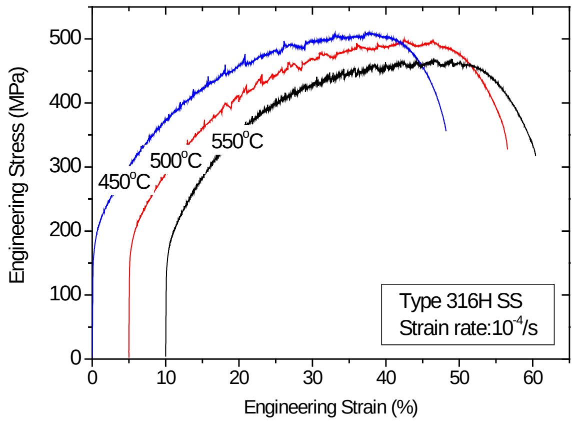

Fig. 8. Stress-strain curves showing dynamic strain aging in Type 316H stainless steel.

4. Summary

The cyclic hardening behavior and ratcheting deformation of Type 316H stainless steel at elevated temperature were investigated in this study. The strongly pronounced strain hardening behaviors were observed at a temperature range 500-575°C as the results of fully reversed cyclic testing and ratcheting testing. It was concluded that the sharp increase in hardening ratio and the retardation of ratcheting strain accumulation in the temperature range was attributed to the DSA manifested by serrated flow observed in tension testing conducted in same temperature range.

REFERENCES

[1] S. J. Zinkle, G. S. Was, Acta Mater. Vol. 61, p. 735, 2013

[2] S.J. Zinkle, N. M. Ghoniem, J. Nucl. Mater., Vol. 417, p. 2, 2011.

[3] M. S. Pham et al., International J. of Plasticity, Vol .47, p. 143, 2013.

[4] A. Sarkar et al., Mater. Sci & Eng. A, Vol. 564, p. 359, 2013.

[5] V. S. Srinivasan et al., Int. J. Fatigue, Vol. 13, p. 471, 1991.