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Cyclic Hardening Behavior of Type 316H at Elevated Temperature

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1. Introduction

It is indispensable to assess the performance of structural materials systematically under the operating condition of sodium-cooled fast reactor (SFR) since SFR operates under the combined condition of much higher temperature and neutron dose comparing to that of conventional reactors [1, 2].

Especially, 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 [3].

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.

Therefore, the ratcheting testing system was constructed and cyclic strain-controlled hardening tests were conducted to obtain material parameters of Type 316H at elevated temperatures those are need for inelastic analysis

The test results will be used for the determination of inelastic material parameters.

2. Experimental

The round type specimens for strain-controlled fully reversed cyclic 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 under a uniaxial, strain controlled mode using triangular waveform. The strain rate and amplitude of the testing were 10^{-4}/s and 0.6 %, respectively.

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

The tension testing were conducted for Type 316H specimens at a temperature range of 450-550°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.

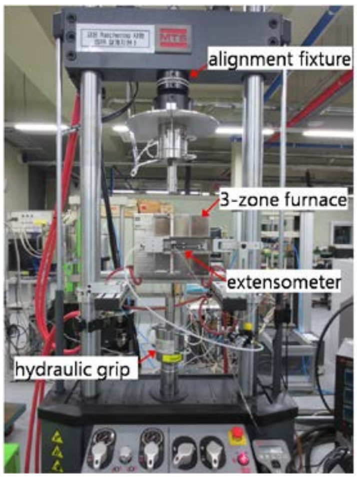

Fig. 1. Cyclic test system equipped with 3 zone furnace, alignment fixture, hydraulic grip and high temperature extensometer.

3. Results and Discussion

The stress-strain hysteresis loops obtained for Type 316H at 650°C is shown in Fig. 1. 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.

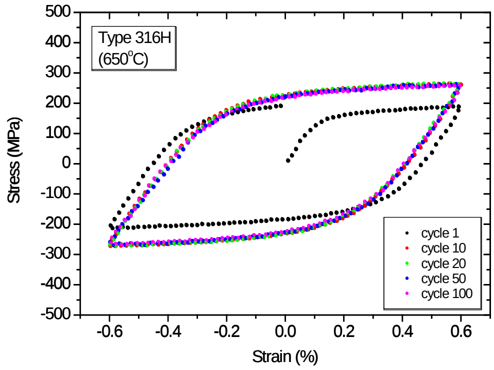

Fig. 2. Stress-strain hysteresis loops for Type 316H stainless steel at 650°C (10^{-4}/s, ±0.6 %).

The maximum stresses as a function of cyclic number at various temperatures were plotted in Fig. 3.

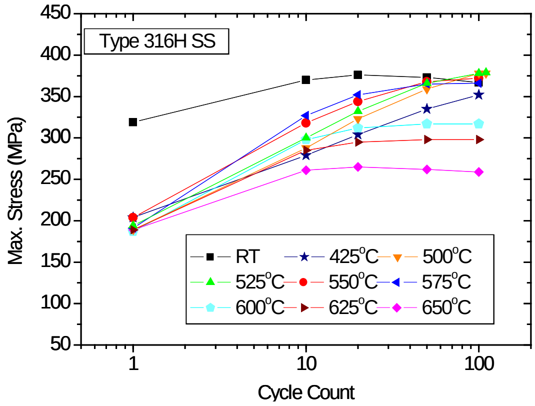

Fig. 3. Maximum stress vs cyclic number for Type 316H stainless steel at various temperatures.

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°C.

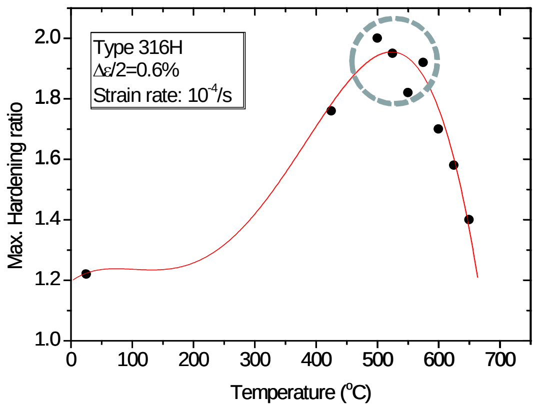

Fig. 4. Maximum cyclic hardening ratio as a function of temperature for Type 316H stainless steel.

It was reported that the hardening magnitude of austenitic stainless steel increased in low cycle fatigue [4] .

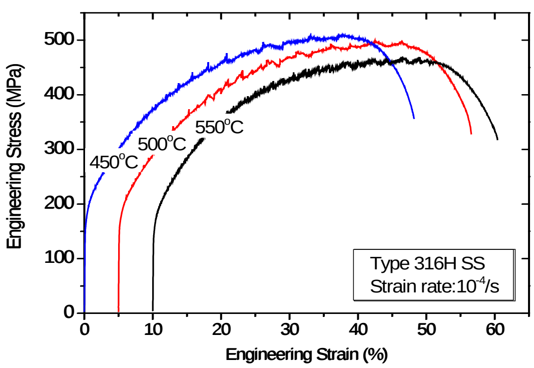

Fig. 5. Stress-strain curve for Type 316H stainless steel at elevated temperatures.

test at elevated temperature due to dynamic strain aging (DSA).

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 in Type 316H stainless steel at 500-575°C was attributed to DSA.

4. Summary

The cyclic hardening behavior of Type 316H stainless steel at elevated temperature was 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. It was concluded that the sharp increase in hardening ratio in the temperature range was attributed to the DSA manifested by serrated flow observed in tension testing conducted in same temperature range.

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