Creep Deformation and Rupture Behavior of Type 316L Stainless Steel

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1. Introduction

Type 316L stainless steel (SS) (“L” grade, C <0.03%) enhanced the grain boundary corrosion resistance and high-temperature properties compared with type 316SS [1]. Since a sodium-cooled faster reactor (SFR) system will be designed for up to 60 years at 550°C, creep rupture behavior is very important. However, creep data of type 316L SS are not available in ASME code [2], and in RCC-MRx [3]. In RCC-MRx, the creep data are only given at 550, 575, 600°C. Therefore, the creep rupture behavior of type 316L SS should be investigated at wide temperature ranges to prepare the design data.

In this study, high-temperature mechanical properties of tension, creep, and creep crack growth (CCG) for type 316L SS were investigated through a systematic analysis using the tested experimental data. Creep deformation and rupture behavior were analyzed various creep equations and parameters: Norton's power law, modified Monkman-Grant (M-G) relation, creep damage tolerance factor (λ), Zener-Hollomon parameter (Z). In addition, an equation for evaluating the CCG for type 316L SS was constructed by the relationships between C^* and da/dt, and it was compared with those of type 316 SS and 316LN.

2. Experimental procedures

Type 316L SS was a hot rolled plate of 25mm thickness, which was solution annealing at 1100°C and water cooling. Chemical compositions are given as C: 0.020, Mn: 1.01, P: 0.030, S: 0.001, Si: 0.42, Ni: 10.03, Cr: 16.77, Mo: 2.04, and N: 0.0043 in wt. %. The tension, creep, and CCG tests were carried out at the high temperatures. The tension tests were performed at the strain rate of 6.67E-4 (1/s) at R.T. to 650°C, using the specimens of a round bar with a 45mm gauge length and 9.0mm diameter. The creep tests were performed under different applied loads at 550, 600, 650, and 700°C, using the specimens of a cylindrical shape with a 30 mm gauge length and 6 mm diameter. The CCG tests were performed at 600°C using 1/2-inch compact tension specimens, which were a 25.4mm width, a 12.7mm thickness, and the side grooves of a 10% depth. Load-line displacement was measured using a linear gauge assembly attached to the specimen, and the crack length was determined using a direct current potential drop (DCPD) technique [4].

3. Results

From the tensile tests, modeling curves for the ultimate tensile strength (UTS) and yield strength (YS) were obtained for the 3rd order polynomial equation. The modelled curves was identified to be similar behavior to RCC-MRx which is currently elevated temperature design (ETD) code in French [3], but the tested data were identified to be higher than RCC-MRx data. From the creep tests, the creep rupture properties were obtained under different stress levels at the four temperatures of 550, 600, 650, and 700°C. The creep rupture data were analyzed using various creep equations: Norton’s power law, modified M-G plot, creep damage tolerance factor, and Z parameter.

Fig. 1 shows a typical result of log (stress) vs. log (rupture time) at four temperatures of type 316L SS. The creep stress shows the results of temperature dependence well. The tested stress are higher than the average rupture stress ($S_{r(moy)}$) in RCC-MRx, but the stress variations with rupture times are similar to that of RCC-MRx.

Fig. 2 shows a result of the creep strain rate obtained at 550, 600, 650, 700°C of type 316L SS. The creep strain rate increases with an increase in temperatures, but creep exponent (n) decreases reversely with temperatures.

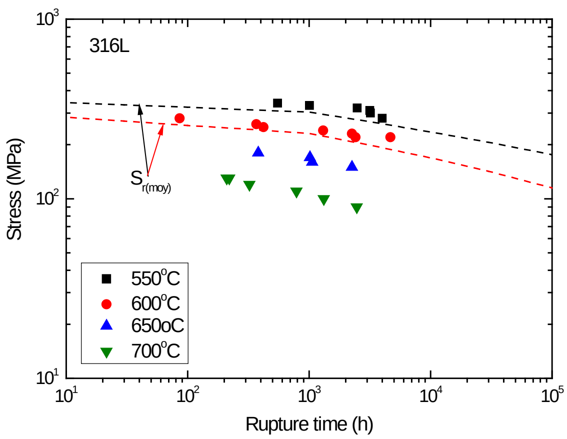

Fig. 1. Plot of stress vs. rupture time at 550, 600, 650, 700°C of type 316L SS

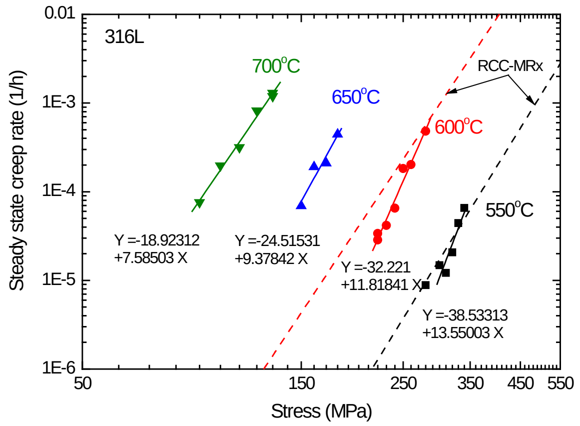

Fig. 2. Plot of creep strain rate at 550, 600, 650, 700°C of type 316L SS

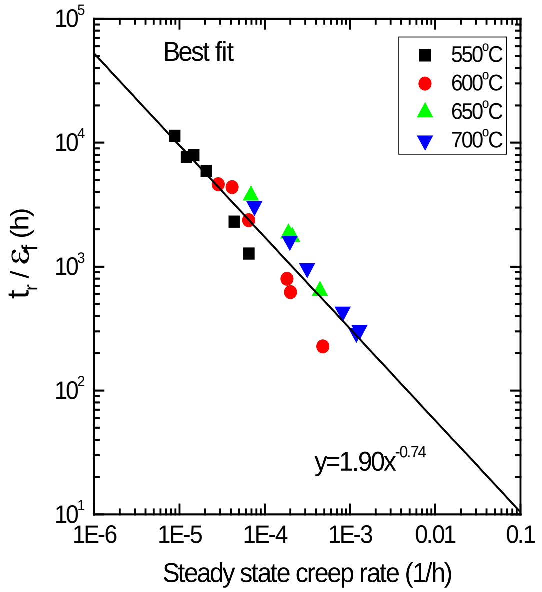

Fig. 3. Plot of modified M-G relationships obtained for type 316L SS

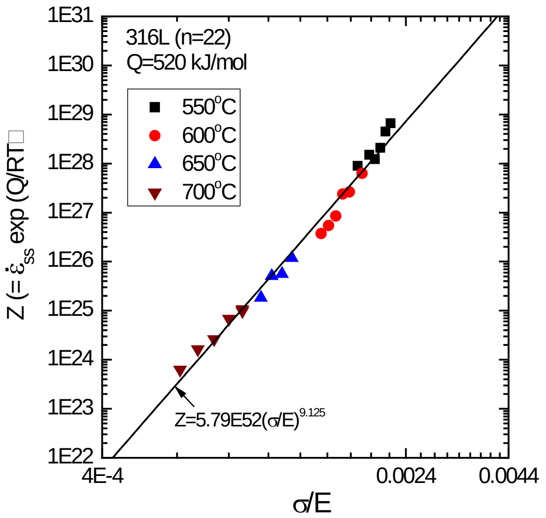

Fig. 4. Plot of Z-parameter vs. (σ/E) obtained for type 316L SS

The tested data at 550 and 600°C are almost similar although the value of creep exponent is some different. In addition, creep damage tolerance factor was identified to be 6.3 for type 316L SS. Fig. 3 presents the result of modified M-G plot obtained for type 316L SS. All of the data obey a good straight line of $y=1.90x^{-0.74}$ regardless of the four temperatures. Fig. 4 shows a plot of Z parameter vs. (σ/E) obtained for type 316L SS. Regardless of four temperatures, the plotted data comply with a good straight line with $Z=5.79E52(\sigma/E)^{9.125}$. Thus, it can be inferred that the same mechanism in creep is operative in the present test ranges.

In addition, from the CCG tests, a model equation for evaluating the CCG rate of type 316L SS at 600°C was obtained as $da/dt = 5.920E\text{-}2(C^*)^{0.877}$. Using the equation, for a given C* value, we can estimate the CCG rate of type 316L SS.

4. Conclusions

The creep rupture stress was higher than the average rupture stress ($S_{r(moy)}$) in RCC-MRx, but the stress variations with rupture times were similar to that of RCC-MRx. The creep strain rate increased with an increase in temperatures, but the creep exponent (n) decreased reversely. Creep damage tolerance factor (λ) was identified to be 6.3 for type 316L SS. All of the data followed modified M-G plot as a good straight line of $y=1.90x^{-0.74}$ regardless of the four temperatures. The Z parameter obeyed a good straight line of $Z=5.79E52(\sigma/E)^{9.125}$. It is thus inferred that the same mechanism in creep was operative in the present test ranges. A model equation for evaluating the CCGR of type 316L SS at 600°C was found to be $da/dt = 5.920E\text{-}2(C^*)^{0.877}$.

Acknowledgment

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References

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