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Generation of Negligible Creep Curve for Type 316L Stainless Steel

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1. Introduction

Types 316 (UNS S31600) and 316L (UNS S31603) stainless steels (SS) are molybdenum-bearing austenitic stainless steels which are more resistance to general corrosion and pitting/crevice corrosion than the conventional chromium-nickel austenitic stainless steels such as Type 304. Type 316L of a low carbon version (0.03%) of austenitic stainless steel 316 is one of the major structural materials for currently operating and a sodium-cooled fast reactor (SFR) because of its good creep strength and tensile properties at elevated temperatures, compatibility with liquid sodium coolant, easy fabrication and weldability. The Gen-IV SFR components will suffer from creep damage during the long service life reaching 50y at the elevated temperatures. "Creep" becomes one of the most critical properties because creep life (or strength) is gradually reduced under the severe conditions of the high temperatures and long duration [1,2]. However, in present, the creep tested data for Type 316L is very lack, and furthermore, there were a few reports only for negligible creep (T_{NEC}) curves defining creep design area [3-5]. To carry out a simple design of the components operating at high temperatures, it is recommended to design in the "no creep" (NC) or "negligible creep" (NEC) temperature regimes of the material. Thus, the T_{NEC} curves for Type 316L are needed to judge disregard creep as design criterion during normal service operation.

In this study, the T_{NEC} curves for Type 316L were proposed by carrying out the long-term life extrapolation using a series of creep experimental data tested at KAERI. The values of a reference stress (σ_{ref}) in tensile yield strength and a stress correction factor (SCF) in creep rupture stress were defined for Type 316L. The validity of proposed negligible creep curves is identified by comparing with RCC-MRx curves.

2. Results and Discussion

2.1 Experimental procedures

Type 316L SS used in this study was a hot rolled plate of 25 mm in thickness manufactured by Dae-Kyeong Company (DKC) in Korea (DKC Heat No.: SC53707). Heat treatment followed solution annealing at 1100°C and water cooling. Chemical compositions (wt.%) are C:0.020, Mn:1.01, P:0.030, S:0.001, Si:0.42, Cr:16.11, Ni: 10.03, Mo:2.04, N: 0.043, and Fe: balance. Amount of each element was included well within ASTM requirement. Creep specimens were prepared for 30mm in gauge length and 6.0 mm in diameter as a round bar type. A series of creep tests was conducted with various applied stresses at 500, 550, 600, 650, and 700°C. Real-time strain data were collected by an automatic data acquisition system through PC. All procedure in creep tests followed ASTM E139.

2.2 Description of negligible creep

The T_{NEC} curves are set based on generating time and temperature of damageable creep strains of each material, and provide diagrams which present the relationship between temperature and accumulated operation time. Creep design area can be settled from the T_{NEC} curves for each material. In case the accumulated operation time at the temperature is short, non-creep design is adopted.

Fig. 1 shows a negligible curve describing the relationship of time and temperature limits below which accumulated creep strain and damage is insignificant at a specified reference or design stress. A blue line indicates a T_{NEC} curve. At the below temperature of the negligible curve, time independent design is done, and at the above temperature, time dependent design is done. At much longer time, creep is developed and finally failed, as indicated with a black line. Also, a red line is NC regime, at the below temperature, time independent design is considered. The NC temperature limits are different for various materials. Time independent rules for design can be applied if the design temperature of a component is restricted below the negligible creep temperature.

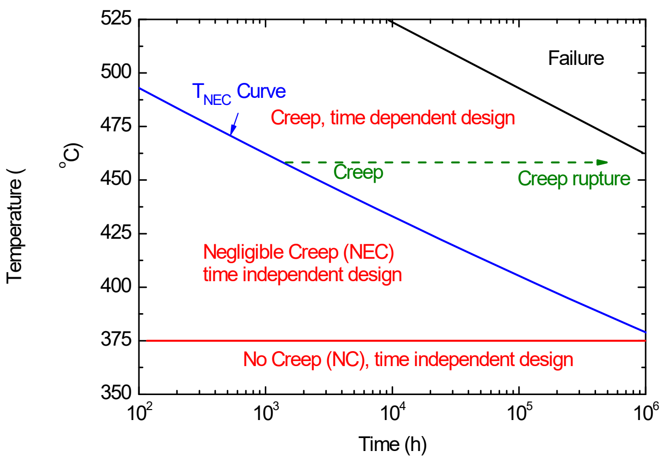

Fig. 1. A detail description for negligible creep curve showing the relationship temperature and time

Negligible creep criteria can be given in ASME [6] and RCC-MRx [7] codes. For Class 1 component, applicable rules in the ASME code are given in subsection NB. These rules are applicable if metal temperatures do not exceed the temperature limits of Section II part D Table 2A.

2.3 Generation of negligible creep curve

To generate the negligible creep curve for Type 316L, long-term creep life extrapolation was performed using experimental creep data of n=30 tested at KAERI, as shown in Fig. 2. In this study, to determine a better method in creep life prediction, the Larson-Miller parameter (LMP) and Wilshire Equation (WE) model were applied and evaluated. Eq (1) is for LMP and Eq. (2) is for WE model [8,9].

$$LMP = (\log t_r + C) \quad (1)$$

$$\sigma/R_m = \exp\,[-k(t_r \exp(-Q/RT))^u] \quad (2)$$

In the results of creep life prediction, the WE model was identified to be superior to the LMP. Thus, this study adopted the WE model for generating T_{NEC} curves for Type 316L. The results of each extrapolation curve are presented at 500, 550, 600, 650 and 700°C, as shown in Fig. 3.

The reference stress (σ_{ref}) has been set at 1.5 R_{p02} for Type 316L SS. The reference stress values of 1.5 R_{p02} for austenitic stainless steel and R_{p02}/1.5 for ferritic/martensitic steels were adopted. Hence, R_{p02} is defined as yield stress (MPa) at specified temperature. This study applied a semi-graphical method for determining the T_{NEC} curve. This method uses tabulated values of creep rupture strength at specified rupture times and temperatures as well as the corresponding yield stress for the definition of the T_{NEC} curve.

The creep rupture strengths $R_{u/t/T}$ (MPa) to time t at temperature T of durations of 1,000, 3,000, 10,000, 30,000, 100,000 and 300,000h are divided by the same correction factor SCF (stress correction factor) of 1.5. The safety on creep rupture is induced by keeping the rupture time the same but lowering the stress by $R_{u/t/T}$ /1.5. The modified rupture and yield curves are plotted against temperature to localize the intersection points. A T_{NEC} curve from intersection points of a σ_{ref} curve and SCF curves is determined. The T_{NEC} curve of Type 316L SS was obtained from Fig. 4. Final results of the T_{NEC} curve obtained for Type 316L SS are presented in Fig. 5. In Fig. 5, a blue line indicates the negligible curve for Type 316L SS. In comparison of Type 316L and Type 316L(N), it is seen that the T_{NEC} curve of Type 316L is located at lower position than that of Type 316L(N). It means that Type 316L(N) is higher in creep strength than Type 316L. Type 316L(N) is longer in negligible creep time than Type 316L. Also, the curves of RCC-MRx code (high-temperature design code in French) are located at lower position than those of this study for Type 316L and Type 316L(N). From the results, it is identified that the T_{NEC} curves of RCC-MRx code are conservative because they are shorter in negligible creep time than those of this study. It is noted that the result of T_{NEC} curve for Type 316L(N) was done in author's previous study [10].

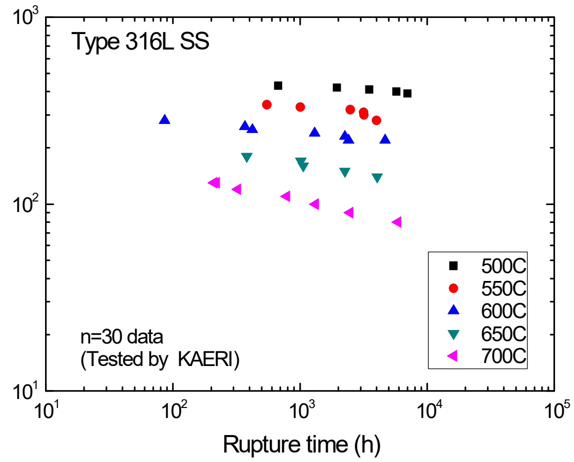

Fig. 2. Experimental creep rupture data obtained at 500, 550, 600, 650, and 700°C for Type 316L SS

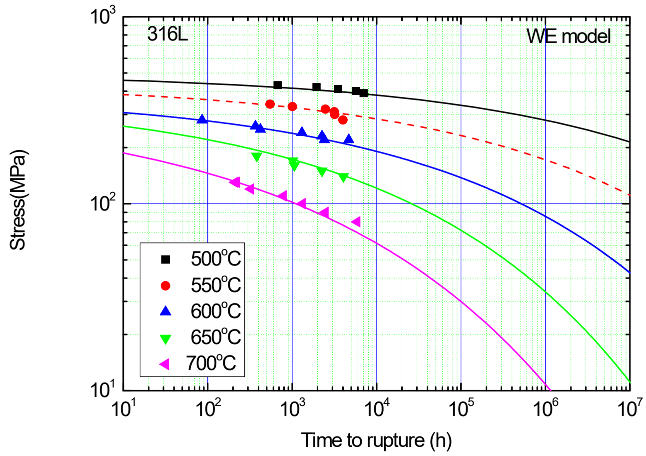

Fig. 3. Results of extrapolated curves at 500, 550, 600, 650 and 700°C for Type 316L SS

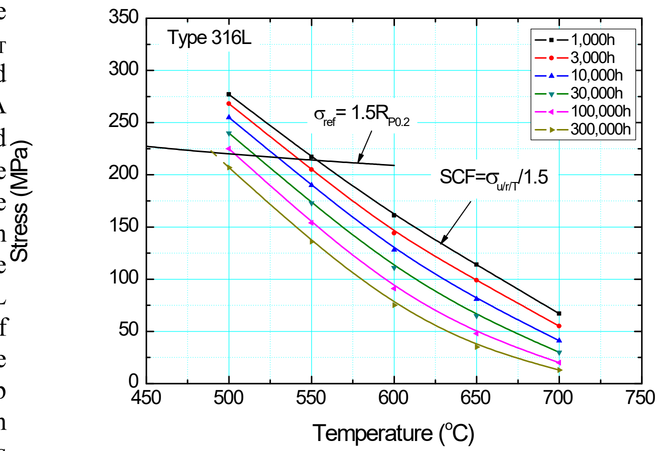

Fig. 4. Result of reference stress and SCF curves for obtaining the T_{NEC} curve for Type 316L SS

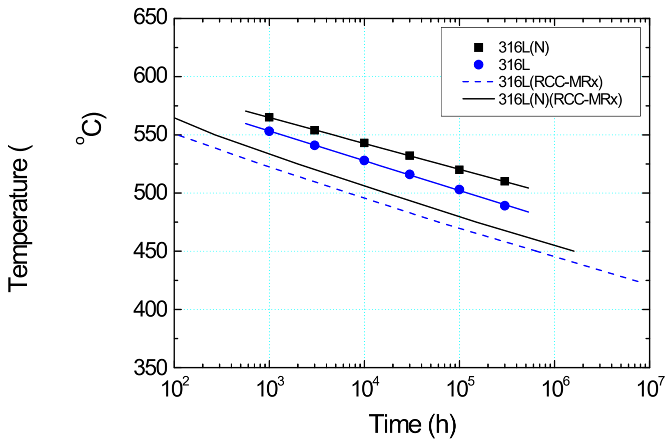

Fig. 5. Result of T_{NEC} curve obtained for Type 316L SS, and comparison of 316L and 316L(N) SS

3. Conclusions

The T_{NEC} curves for Type 316L were proposed by carrying out the long-term life prediction using a series of creep experimental data tested at KAERI. The values of a reference stress (σ_{ref}) in tensile yield strength and a stress correction factor (SCF) in creep rupture stress were defined for Type 316L. The validity of proposed negligible creep curves was identified by comparing with that of RCC-MRx code curves. The T_{NEC} curves given in RCC-MRx code were conservative because they was shorter in negligible creep time than that of this study

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