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Prediction of Creep Design Stresses for Type 316L Stainless Steel

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1. Introduction

Type 316L stainless steel (SS) 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. The long-term creep rupture stress data above 10^5h will be needed to design the components used for Type 316L steel. However, in present, the creep rupture data have not widely reported at low and high temperature ranges. Especially, in RCC-MRx code (typical high-temperature design code in France) [1], the data provide for only the three temperature at 550, 575, 600°C, and it was not given at 500, 650 and 700°C. Therefore, it is necessary to provide the long-term creep rupture stresses for wide-temperature ranges of 500 to 700°C for designing of Type 316L SS.

In this study, the values of average creep rupture stresses for Type 316L SS are preliminarily predicted by creep interpolation and extrapolation of Larson-Miller Parameter using a series of creep rupture data collected from KAERI tested data, ECCC (European Creep Collaborative Committee) data, and RCC-MRx data, and then, the values of minimum creep rupture stresses for design use are proposed. The results are compared with the data values given in RCC-MRx code.

2. Results and Discussion

2.1 Preparation of creep rupture data

Creep rupture data for Type 316L SS were collected (total data points, n=66) at 500, 550, 600, 650, and 700°C from KAERI data, ECCC data [2], and RCC-MRx data [1], as shown in Fig. 1. In Fig. 1, the KAERI data were obtained from creep experimentation in KAERI, the ECCC data were obtained for the long-term data reaching 200,000h at 500, 550, 600, and 650°C from ECCC data sheet [2], and RCC-MRx data were obtained 550, 600°C from RCC-MRx code [1]. Using the collected data, long-term creep stresses were predicted by Larson-Miller Parameter (LMP), and the predicted stresses were compared to the RCC-MRx code data. The short-term data under 10h were excluded for creep life extrapolation.

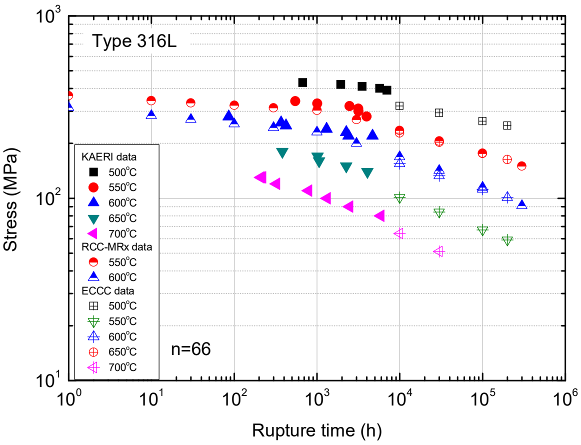

Fig. 1. Creep rupture stress data (n=66 points) collected at wide temperature ranges for Type 316L SS

2.2 Creep life extrapolation

To predict long-term creep rupture stresses, Larson-Miller Parameter model was used, and it is given as Eq. (1) [3].

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

Herein, an optimum value for a constant C was determined as C=18. In the results of creep life prediction, each predicted curve as average creep stresses (ACS), as shown at 550, 550, 600, 650, 700°C in Fig. 2, exhibits good agreement with the rupture data.

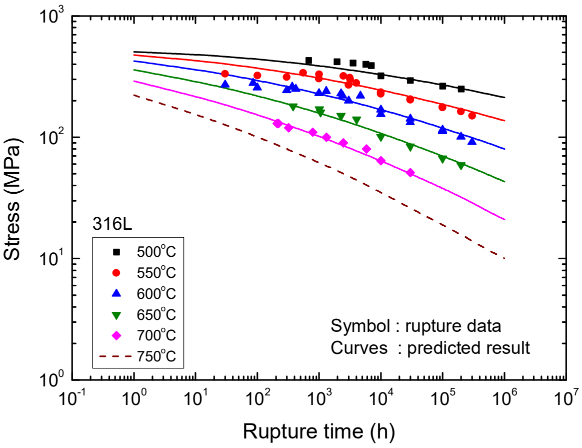

Fig. 2. Average creep rupture stress curves predicted at 500, 550, 600°C, 650°C, 700, and 750°C for Type 316L SS

In the plot, the creep rupture stress at 750°C was predicted, as indicated with the dotted lines. In the prediction of average creep stress curves, it is identified to be good match with RCC-MRx code data.

In addition, a minimum creep stress (MCS) value which can be used as creep design stress was predicted from the ACS curves. The MCS values were obtained from the master curve of a lower prediction limit (LPL) with 95% reliability, as shown in Fig. 3. It is indicated as a red line. From the master curve of the LPL line in Fig. 3, the minimum creep rupture stress curves (or values) can be predicted at each temperature, as shown in Fig. 4. A predicted curve for the minimum creep stress reveals a good match with RCC-MRx code data, as shown in Fig. 5. It is thus justified that the MCS values using LPL lines with 95% reliability can be used to determine a minimum creep design stress.

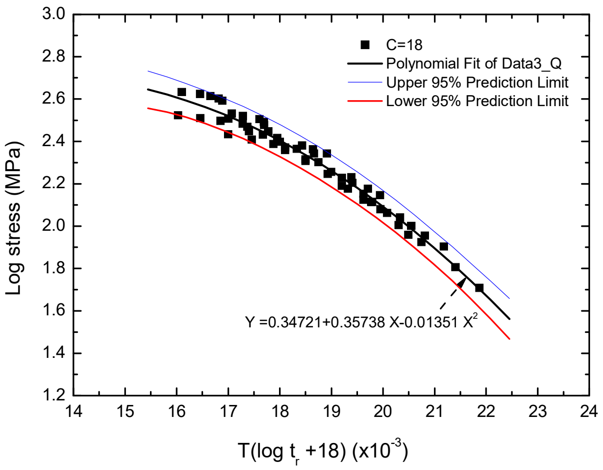

Fig. 3. A master curve of the LPL curve (red line) with 95% reliability from ACS curve (black line)

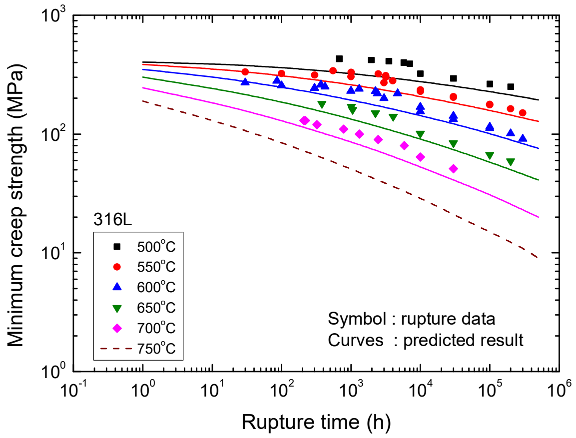

Fig. 4. Minimum creep rupture stress curves predicted at 500, 550, 600°C, 650°C, 700, and 750°C for Type 316L SS

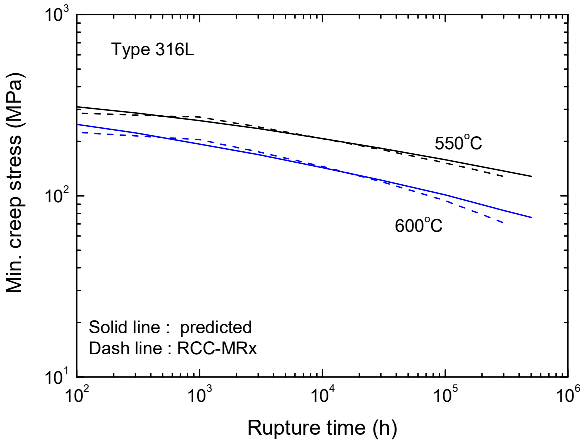

Fig. 5. Comparison of predicted results to RCC-MRx data at 550, and 600°C for Type 316L SS

3. Conclusions

To determine the creep rupture stress values for Type 316L SS, long-term creep life extrapolation was performed by the LMP model using the collected creep rupture data from KAERI, ECCC and RCC-MRx data. In the results, the predicted average creep stress values showed a good match with RCC-MRx code data. For design use, the minimum creep rupture stresses were reasonably proposed at each temperature using the master curve of a lower prediction limit (LPL) with 95% reliability. It is identified that the LPL line with 95% reliability can be reasonably applied to determine minimum creep rupture stress values.

Acknowledgements

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