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Long-term Creep Life Prediction for Type 316LN Stainless Steel

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1. Introduction

Since Sodium Fast Cooled Reactor (SFR) components are designed to be use for more than 30 years at a high temperature of 550°C, one of the most important properties of these components is the long-term creep behavior [1, 2]. To accurately predict the long-term creep life of the components, it is essential to achieve reliable long-term test data beyond their design life. But, it is difficult to actually obtain long duration data because it is time-consuming work.

So far, a variety of time-temperature parameters (TTPs) have been developed to predict a long-term creep life from shorter-time tests at higher temperatures. Among them, the Larson-Miller, the Orr-Sherby-Dorn, the Manson-Harferd and the Manson-Succop parameters have been typically used [3, 4]. None of these parameters has an overwhelming preference, and they have certain inherent restrictions imposed on their data in the application of the TTPs parameters. Meanwhile, it has been reported that the Minimum Commitment Method (MCM) proposed by Manson and Ensign [5, 6] has a greater flexibility for a creep rupture analysis. Thus, the MCM will be useful as another approach. Until now, the applicability of the MCM has not been investigated for type 316LN SS because of insufficient creep data.

In this paper, the MCM was applied to predict a long-term creep life of type 316LN stainless steel (SS). Lots of creep rupture data was collected through literature surveys and the experimental data of KAERI. Using the short-term experimental data for under 2,000 hours, a longer-time rupture above 10^5 hours was predicted by the MCM at temperatures from 550°C to 800°C.

2. Methods and Results

2.1 Determination of constant A

Creep-rupture data for type 316LN SS was collected from worldwide literature surveys [7]; Japan, India, Czechoslovakia and Korea. This data was selected from that which clearly defined by chemical compositions with the *nitrogen content* in the 0.06~0.15wt.% ranges. The total number of data was 345 points, and the temperature range was from 500 to 800°C.

The MCM eqn. has the form of

$$\log t + AP(T)\log t + P(T) = G(\log\sigma) \qquad (1)$$

where t is the rupture time and A is a material constant relating to a structural stability, $P\ (T)$ is a temperature function, and $G\ (\sigma)$ is a stress function. The value of stability factor A is a single constant. If the A and the P function are known, the G function can be determined simply. But, to solve eqn. (1) is complicated by a nonlinear form, resulting from the product of an unknown A and P function. To determine the A value, two methods were demonstrated in this study.

Firstly, the "focal point method" was adopted. Log t_1 and log t_2 were taken from a point intersected with isothermal lines at equal stress levels in a typical log σ–log t plot. Then, the A value can be obtained at a convergent point of each extended isothermal line. But, the data did not create a convergent point for the extended isothermal lines. So, the A value was determined by taking a reciprocal of the mean slope of each isothermal line between log t_1 and log t_2. Its value for the focal point method was -0.089.

Secondly, the "trial and error method" was adopted to determine the optimum value of the A. A series of A values are chosen from a wide range of -0.15 to 0.15. From a series of the A values, by using eqn. (1), a polynomial equation is obtained by best fitting the data in the plot of the log σ and the G function. Then, a proper value for the A was determined by using a statistical parameter of the coefficient for the determination, R^2, indicating whether the polynomial equation is a good or bad conformation for the data. If the R^2 value is high, it means a good match to the data.

Fig. 1 shows the results of the R^2 values with respect to the A values obtained by the trial and error method. An optimum value for the A was found to be -0.02 to -0.05. This study used the value of A=-0.05. Meanwhile, it was identified that the value of A = -0.089 obtained by the focal point method was not proper, because the R^2 value was low.

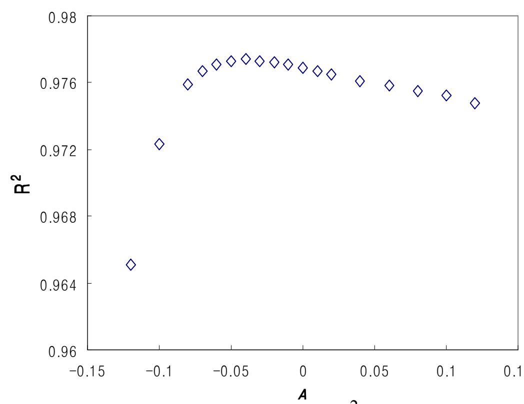

Figure 1. Variations of R^2 with A values

2.2 Determination of the P and G function

The P function has the form of eqn. (2) [6],

$$P(T) = R_1(T - T_m) + R_2(1/T - 1/T_m) \qquad (2)$$

where R_1 and R_2 are constants, and T_m is the absolute temperature in the midrange of the experimental data. We used 923K (650°C) as the midrange between 550°C and 800°C. Substituting eqn. (2) into eqn. (1) and by re-arranging it, we can get eqn. (3) as

$$\frac{(\log t_2 - \log t_1)}{M} = \frac{N}{M} R_2 + R_1 \qquad (3)$$

Hence, $M = A[(T_1 - T_m)\log(t_1) + (T_2 - T_m)\log(t_2)] + (T_1 - T_2)$ (4)

$$N = A\left[\left(\frac{1}{T_1} - \frac{1}{T_m}\right)\log(t_1) + \left(\frac{1}{T_2} - \frac{1}{T_m}\right)\right]\log(t_2) + \left(\frac{1}{T_1} - \frac{1}{T_2}\right) \qquad (5)$$

Since the M and N are known at each point, then we can plot (log t_2-log t_1)/M vs. N/M. The R_1 becomes the intercept and the R_2 is the slope of the resulting straight line.

The R_1 and R_2 values were obtained by a linear equation. In the case of A=-0.05, the R_1 value was -0.0472 and the R_2 value was -69,457. The A and the P function were obtained by using the data for under 2,000 hours. Also, the G function was determined by using the known A and P function. For every available datum point, all the terms on the left side of eqn. (1) are known since log t, A, and P for the temperature are known. Thus, the G can be calculated for each datum point. Then, these values can be plotted against the values of logσ to obtain the curve.

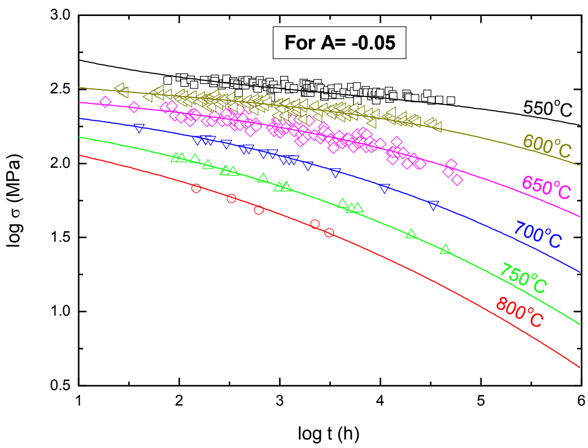

Figure 2. Results of creep-life prediction with temperatures in A =—0.05

2.3 Creep-life prediction with the A values

Fig 2 shows the results of the creep-life prediction with various temperatures for A =-0.05. Long-time rupture is predicted well up to 10^6 hours for each temperature from 550°C to 800°C. Each prediction curve shows a good match with the experimental data without any differences in all the temperature ranges. However, from an example of A=-0.07 at 750°C, it was identified that the prediction curve was not matched with the experimental data.

3. Conclusion

The MCM was applied to predict the creep rupture life of type 316LN SS. Constants A, and the P (T) and (σ) functions being used in the MCM equation were determined. An optimum value of A was found to be from -0.02 to -0.05 for type 316LN SS. The prediction curve for A=-0.02~-0.05 showed a good match with the experimental data without any differences in all the temperature ranges, but the curve for A=-0.07 at 750°C did not show a good match with the data of a longer-time rupture. Long-time rupture reaching 10^6 hours from the short-time data of under 2,000 hours was predicted by the MCM well.

REFERENCES

[1] W. G. Kim, S. H. Kim and W. S. Ryu, Evaluation of Monkman-Grant Parameters for Type 316LN and Modified 9Cr-Mo Stainless Steels, KSME Int. J., Vol.16, p. 420, 2002.
[2] W. G. Kim, S. H. Kim and W. S. Ryu, Creep Characterization of Type 316LN and HT-9 Stainless Steels by the K-R Creep Damage Model, KSME Int. J., Vol.15, p.1463, 2001.
[3] VAMAS Data Evaluation Committee: Iron and Steel Institute of Japan, 1994.
[4] I. Le May, Developments in Parametric Methods for Handling Creep and Creep-Rupture Data, Transactions of the ASME, Vol. 101, p. 326, 1979.
[5] S. S. Manson and C. R. Ensign, Specialized Model for Analysis of Creep Rupture Data by the Minimum Commitment Method, Station-Function Approach, NASA TM X-52999, p. 1, 1971.
[6] S. S. Manson and C. R. Ensign, Interpolation and Extrapolation of Creep Rupture Data by the Minimum Commitment Method-Part 2, MPC-7 ASME NY, p. 299, 1978.
[7] W. G. Kim, S. N. Yin and W. S. Ryu, Application and Standard Error Analysis of the Parametric Methods for Predicting the Creep Life of Type 316LN SS, Key Engineering Materials, Vol. 297~300, p.2272, 2005.