Creep-Life Prediction of Type 316LN Stainless Steel by Time-Temperature Parametric (TTP) Methods

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1. Introduction

Type 316LN stainless steel (SS) is a candidate material for major structural components of liquid metal reactor (LMR) because of their good high-temperature mechanical properties. Since the LMR components are used for 20 to 30 years at high temperature up to 550°C, one of the most critical factors of the components is creep -rupture life due to long duration [1,2].

So far, a variety of parameters have been developed for predicting long-term creep life. Typically, Larson-Miller (L-M), Orr-Sherby-Dorn (O-S-D), Manson-Harferd (M-H), Manson-Succop (M-S), and Goldhoff-Sherby (G-S) parameters have been well used. These parameters are basically established by time-temperature parameter (TTP) [3,4,5]. In use of these parameters, each method has merits and demerits with different material cases. Also, because the stability of metallurgical structure can be not assured when materials are damaged due to thermal-mechanical effect during long period, any parameters are not perfect in predicting creep life. Thus, it is necessary to analyze acceptibality of each parametric method.

In this paper, many creep rupture data for type 316LN SS are collected through literature survey and experimental data, and these data are applied to typical L-M, O-S-D and M-H parametric methods. Polynomial equations for predicting creep rupture life are obtained for three parameters, respectively. To identify an acceptance of each parameter, standard error of estimate (SEE) values are analyzed for different temperatures by statistical process of the creep data.

2. Methods and Results

2.1 TTP methods

TTP methods depend on the interrelation of time and temperature in contributing to creep deformation. Time and temperature variables are combined into one parameter. Parameter, P is expressed as a function of a stress as following equation (1). A plot of log (stress) versus the parameter produces a single curve or line. Longer-time rupture behavior can be predicted by extrapolation of the single curve.

$$P\,(t_r, T) \;=\; f(\sigma) \qquad (1)$$

Each equation of L-M, O-S-D and M-H parameters used in this study can be written as follows.

$$\text{L-M}: \; P(t_r, T) = (\log t_r + C)T \qquad (2)$$

$$\text{O-S-D}: \; P(t_r, T) = \log t_r - \frac{Q}{2.3RT} \qquad (3)$$

$$\text{M-H}: \; P(t_r, T) = \frac{\log t_r - \log t_a}{T - T_a} \qquad (4)$$

Where, C, Q, t_a and T_a are constants, and R is universal gas constant. In addition, a stress function of x-axis can be expressed by a polynomial equation as follows.

$$f(\sigma) = b_o + b_1 \log(\sigma) + b_2 (\log\sigma)^2 + \cdot\cdot b_k (\log\sigma)^k \qquad (5)$$

Where, k is order in the polynomial equation, and b_k is regression coefficient for k order.

2.2 Creep-life prediction of type 316LN SS

In order to predict creep life of type 316LN SS, a number of creep rupture data were collected through literature survey or experimental data produced in KAERI, as seen in Figure 1. Using the collected data, each polynomial equation for predicting creep life was obtained for L-M, O-S-D and M-H parameters.

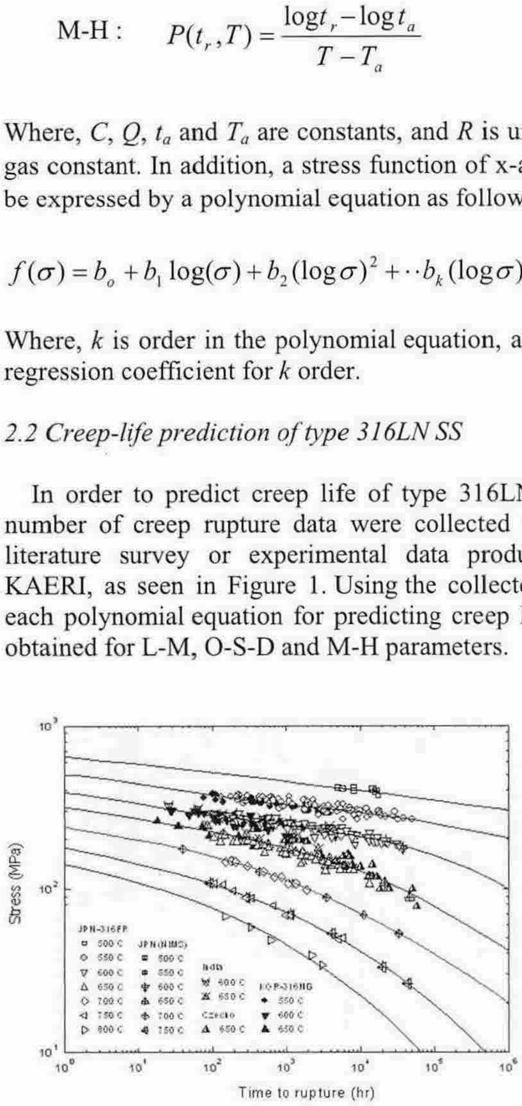

Figure 1. Stress vs. time to rupture of type 316LN SS.

The equation for predicting creep life was compared for three parametric methods using relative standard error (RSE) value, respectively. It is defined by the following equation (6),

$$RSE = \sqrt{\sum_{i=1}^{i=n} \left(\frac{Y_i - \hat{Y}_i}{\hat{Y}_i} \right)^2 / (n - n_p)} \qquad (6)$$

Where, $\hat{Y}_i$ is estimated average value, and n is total number of creep data. n_p is number of an uncertain coefficient included in the regression equation.

RSE value of the regression equation for predicting creep life did not show a large difference with each parametric method. Thus, it is believed that the three parametric method can be used for predicting creep life of type 316LN SS

2.3 Analysis of standard error of estimate

To analyze acceptability of the regression equations for each parameter, SEE value was obtained. Its value is defined by the following equation (7),

$$SEE = \sqrt{\sum_{i=1}^{i=n} (Y_i - \hat{Y}_i)^2 / (n - n_p)} \qquad (7)$$

SEE value for each parameter was obtained with different temperatures of 550, 600, 650 and 700°C. The summary of SEE values was listed in the Table 1 and typical results are presented in Figures 2 and 3. The results of three parametric methods do not generate a large difference with temperatures, but M-H showed significantly low value comparing with L-M or O-S-D. The reason for this is because M-H parameter includes two constants of t_a and T_a. Thus, it appears that M-H is superior in temperature acceptability to L-M and O-S-D.

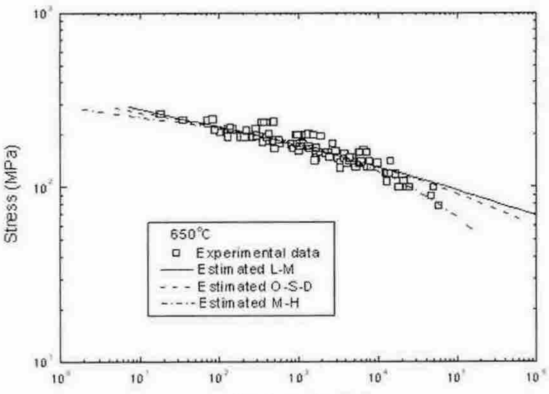

Figure 2. Comparison of L-M, O-S-D and M-H methods on experimental data and estimated line at 650°C.

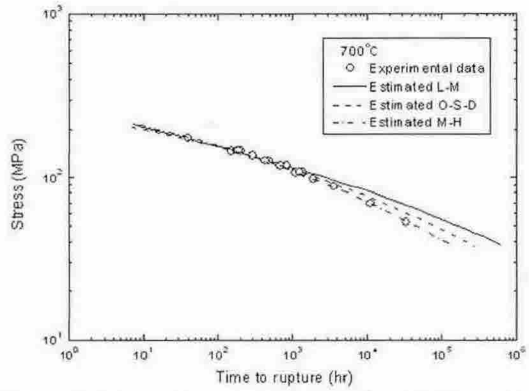

Figure 3. Comparison of L-M, O-S-D and M-H methods on experimental data and estimated line at 700°C.

Table 1 Comparison on SEE values of each parameter.

Temp.(°C)	SEE values for log t_r		
	L-M	O-S-D	M-H
550	0.3823	0.3795	0.4066
600	0.3443	0.3280	0.3340
650	0.3649	0.3629	0.3640
700	0.2212	0.1251	0.0636

3. Conclusion

Polynomial equations for predicting creep life were obtained for L-M, Q-S-D and M-H parametric methods. SEE values for each parameter were obtained by the statistical process using a number of the creep data for type 316LN SS. The results of L-M, O-S-D and M-H parameters showed good creep-life prediction, but M-H method showed better agreement than L-M and O-S-D methods. Especially, it was found that SEE values of M-H method at 700°C were lower than that of L-M and O-S-D methods.

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