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Estimation of Creep Behavior of Alloy 690 Based on the Power Law Creep Models

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1. Introduction

Creep deformation and life prediction model for Alloy 690 steam generator tube material has been developed to respond the postulated severe accident behavior. Even though MELCORE code accepts a simple Larson-Miller parameter (LMP) model [1], power law creep models have been generally used to describe the high temperature deformation from theoretical and experimental point of views [2]. In this study, a two-step optimization procedure is proposed to improve the accuracy of the power law creep model with the experimental data of Alloy 690 steam generator tube material.

2. Material and Experiments

The test material is a Ni-Cr-Fe alloy, which is designated as Alloy 690 for PWR SG tubes. The dimensions of tubes are 19.05 mm in outer diameter and 1.07 mm in thickness. The test specimens were machined from the tube with the gage length of 18mm and gage width of 4mm in longitudinal direction.

A series of creep rupture tests were conducted in the temperature range of 650~850°C. Steady-state creep rates and rupture times were measured at various combinations of the applied stress and temperature [3]. Creep tests were conducted under a constant load condition.

3. Parameter Optimization of Power Law Creep

Power law creep models can be simply presented as the following equation [2]:

$$\dot{\varepsilon}_{ss} = B \cdot \sigma^n \qquad (1)$$

where *B* and *n* are the power law creep parameters, which depend on temperature. $\dot{\varepsilon}_{ss}$ is the steady-state creep rate at a test condition.

Fig. 1 shows the relations between the measured steady-state creep rate and the applied stress in a logarithmic scale. At each temperature, the power law relationship is well demonstrated by the straight lines in a logarithmic scale. The slope of each data set, which represents the stress exponent *n*, varies from 3.8 ~ 6.6 increasing with a temperature decrease. The y-axis intercept represents the value of log(*B*) at the temperature. Conventionally, the values of *n* and log(*B*) are simply determined by using a linear function at each temperature.

The most important finding of this study is that the two parameters, *n* and log(*B*), should be optimized one-after-another at each temperature. This procedure could significantly improve the prediction capability of power law creep model. The authors call it a two-step optimization procedure of power law creep model.

Step-1) Just like a conventional procedure, determine the *n* value at every temperature from the measured steady-state creep rate with the applied stress as shown in Fig.1. The *n* values are fitted to an arbitrary function of temperature, *n*=*f*(T).

Step-2) Optimize the data sets again after fixing *n* values with the fitted values, *f*(T) at each temperature. At this stage, only the parameter *B* is optimized with the same data sets. Then the re-optimized log(*B*) values should be fitted to another function of temperature, log(*B*)=*g*(T).

4. Accuracy Improvement of Proposed Method

The optimized functions of *f*(T) and *g*(T) are as follows for the tested material in the longitudinal direction.

$$\mathrm{f(T)} = 559.91 \times \exp\left(-\frac{\mathrm{T}}{128.135}\right) + 3$$

$$\mathrm{g(T)} = 5.10931 - 971.45 * \exp(-\frac{\mathrm{T}}{149.58})$$

where units are °C, MPa and 1/hr.

Fig. 2 compares the measured data of the steady-state creep rates to the ones predicted by the proposed model. The standard deviation of the prediction error was only 20%, which is considered good enough in predicting the engineering creep data.

Fig. 3 is a similar plot to Fig. 2, while the power law parameters were determined by the conventional 1-step method. The standard deviation of the prediction error in Fig. 3 was 38.6%. Comparing Fig. 2 with Fig. 3, the new procedure proposed in this study showed a dramatical improvement in the prediction of the steady-state creep rates by using a power law model.

The improvement in prediction accuracy may be used to develop more sophisticated and comprehensive model for high temperature deformation and life prediction.

5. Conclusions

A new procedure to optimize parameters of power law creep models is proposed for the experimental data of Alloy 690 SG tube material. Both the stress exponent *n* and the rate constant *B* are simply treated as the temperature dependent parameters. The most important concept is a two-step optimization procedure for determination of the rate parameter *B*. The temperature function of the rate constant *B*(T) should be optimized for the *B* values obtained after fixing the stress exponent *n* with the prior optimized function values at each temperature. The new procedure could significantly reduce the prediction errors of the power law creep model.

REFERENCES

[1] Y. Liao, K. Vierow, MELCOR analysis of steam generator tube creep rupture in station black out severe accident, Nucl. Technol. 152 (2005) 302-313.
[2] M.E. Kassner, Fundamentals of Creep in Metals and Alloys, Elsevier, Amsterdam, 2009.
[3] B.S. Lee, J.M. Kim, J.Y. Kwon, K.J. Choi, M.C. Kim, A Practical Power Law Creep Modelling of Alloy 690 SG Tube Materials, Nuclear Engineering and Technology (in print) https://doi.org/10.1016/j.net.2021.03.004.

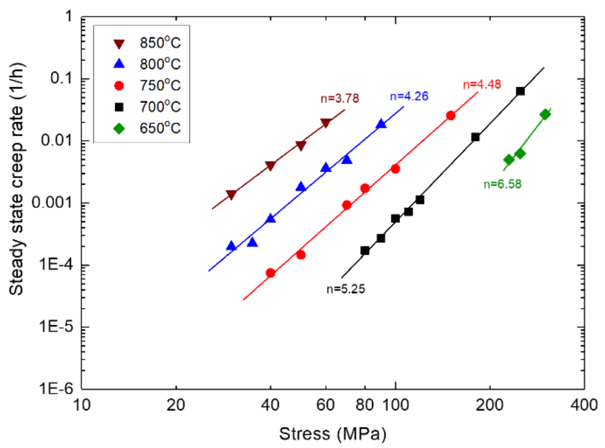

Fig. 1. Power law creep analysis of Alloy 690 SG tube material test data [3].

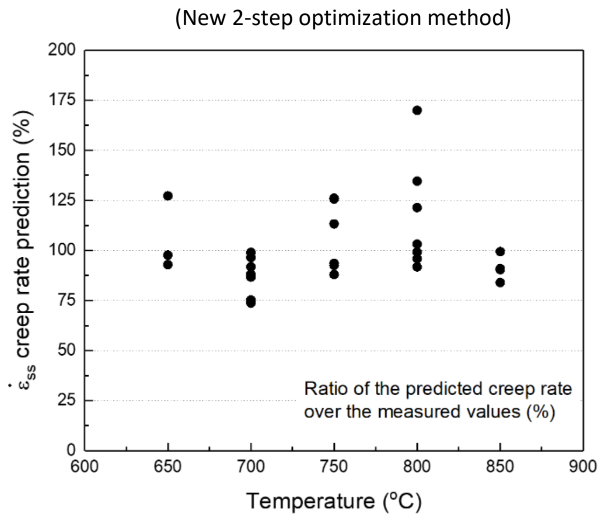

Fig. 2. Comparison of the steady-state creep rates predicted by the proposed model to the measured data at different temperatures.
(New 2-step optimization method).

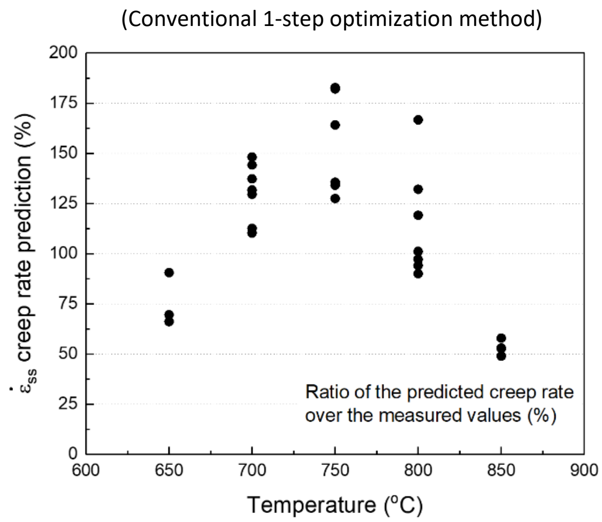

Fig. 3. Comparison of the steady-state creep rates predicted by the proposed model to the measured data at different temperatures.
(Conventional 1-step optimization method).