Description of Creep Strain-Time Curves by Nonlinear Fitting Method in the K-R Model

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1. Introduction

Time-dependent creep behavior is very important for designing the metallic components of a high temperature gas cooled reactor (HTGR) such as the hot gas ducts and intermediate heat exchanger (IHX) tubes, because the integrity of these components should be preserved during a design life of over 30 years at a high temperature reaching of up to 1000°C [1].

Hastelloy-X (HX) alloy (UNS NO. N06002), a nickel-chromium-iron-molybdenum alloy is considered as a candidate material for the IHX of the HTGR, because it possesses an exceptional combination of oxidation resistance, fabricability and high temperature strength. Nickel-base alloys or high chromium alloys may start a tertiary creep at a low strain range under 1% strain, and the tertiary creep may govern a creep deformation [2]. In order to describe the creep curve for the HX alloy, a proper equation for the tertiary creep is needed. As a proper model for the tertiary creep, the Kachanov-Rabotnov (K-R) model has been frequently used for metallic materials. Thus, it is necessary to investigate the applicability of the K-R model for the HX alloy.

In this paper, the creep curves for the HX alloy were described by using the nonlinear least square fitting (NLSF) method in the K-R model. An optimum value for the λ parameter of the K-R model was obtained with stress variations, and the relationship between the λ and stress was investigated.

2. Methods and Results

2.1 Nonlinear fitting for K-R model

Creep data for the HX alloy was obtained from the creep tests with different stress levels, 35MPa, 30MPa, 25MPa, 20MPa, 18MPa, 16MPa and 14MPa at 950°C. The HX alloy showed good creep ductility, and the ductility values decreased as the applied stresses decreased. Using the creep data, the creep curves are obtained by the NLSF method in the K-R model.

Generalized K-R eqns. are as follows [3-5],

$$\frac{\varepsilon}{\varepsilon_r} = 1 - \left(1 - \frac{t}{t_r}\right)^{1/\lambda} \quad (1)$$

$$\frac{\varepsilon}{\varepsilon^*} = \lambda \left[1 - \left(1 - \frac{t}{t_r}\right)^{1/\lambda}\right] \quad (2)$$

$$\varepsilon^* = \dot{\varepsilon}_o \cdot t_r \quad (3)$$

$$\varepsilon_r = \lambda \cdot \varepsilon^* \quad (4)$$

where, ε_r and t_r are the rupture strain and rupture time, respectively, and λ is a constant. Also, $\dot{\varepsilon}_o$ is the creep strain rate for a range of stresses and ε^* is the Monkman -Grant (M-G) parameter. In the K-R model, the λ parameter is an important constant regarded as a creep resistant feature of a material. The shapes of the creep curve can be plotted by eqns. (1) and (2).

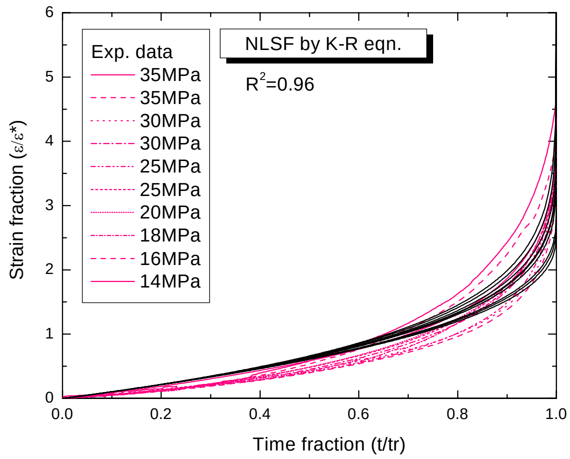

Figure 1. Strain fraction vs. time fraction by NLSF of the K-R equation.

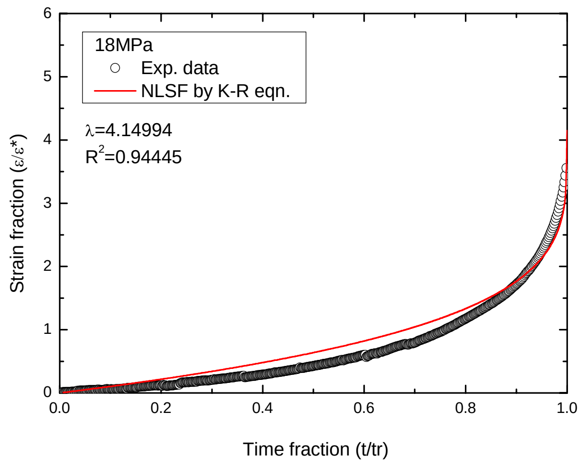

Figure 2. Comparison between experimental data and NLSF of K-R equation in 18MPa.

Fig. 1 shows the results between the normalized representation of K-R eqn. (2) and all the experimental creep data. In this study, in order to obtain an optimum value for the λ parameter of K-R eqn. (2), the nonlinear least square fitting (NLSF) method was employed. A calculation was carried out by using the "Nonlinear

Curve Fit" and "Advanced Fitting Tool" of Origin 7.5 version. The master curves of the creep strain fractions ($\varepsilon/\varepsilon^*$) at various life fractions (t/t_r) did not show good agreement with the experimental data, and also, as shown in Fig. 2 which is plotted for a typical result of 18 MPa. However, it is believed that the NLSF method revealed approximate agreement because the average value of coefficient of determination, R^2, which means a statistic parameter [6], was 0.96. The λ value was not changed as a function of the stress, and the average value taken from all the data was about 3.9.

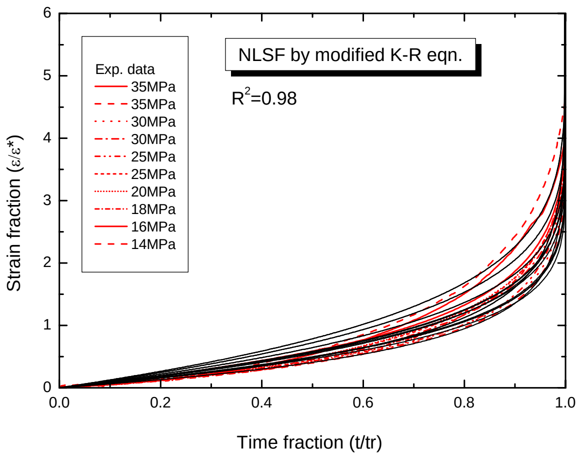

Figure 3. Strain fraction vs. time fraction by NLSF of the modified equation.

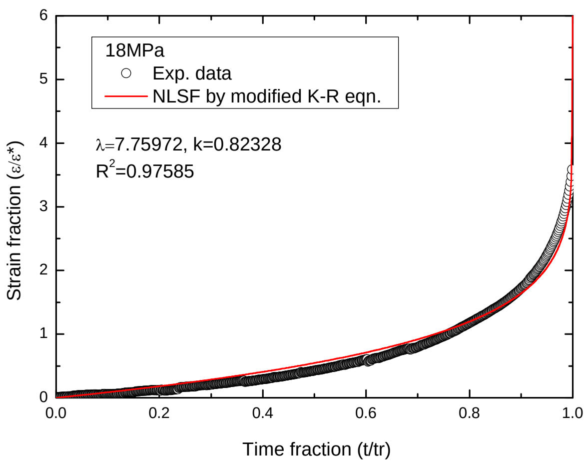

Figure 4. Comparison between the experimental data and NLSF of the modified equation at 18MPa.

2.2 Nonlinear fitting for modified K-R model

In order to obtain a closer creep curve to the experimental data, a modified K-R eqn. was employed,

$$\frac{\varepsilon}{\varepsilon^*} = K, \lambda \left[1 - \left(1 - \frac{t}{t_r} \right)^{1/\lambda} \right] \qquad (5)$$

where, K is a correction coefficient. Because eqn. (5) has another variable K in eqn. (2), it can be superior for a description of the creep curves to the K-R model.

Fig. 3 shows the results of the normalized representation of modified eqn. (5) when compared to all the experimental creep data. The master curves of the modified K-R eqn. represent better agreement that those of the K-R one. As a typical result of 18 MPa, the fitting result of the modified K-R one is much closer to the experimental data, as shown in Fig. 4. The average value of the R^2 for the modified one was improved with 0.98. Also, the λ parameter showed the behavior of a stress independence and the average value was about 5.82, as shown in Fig. 5.

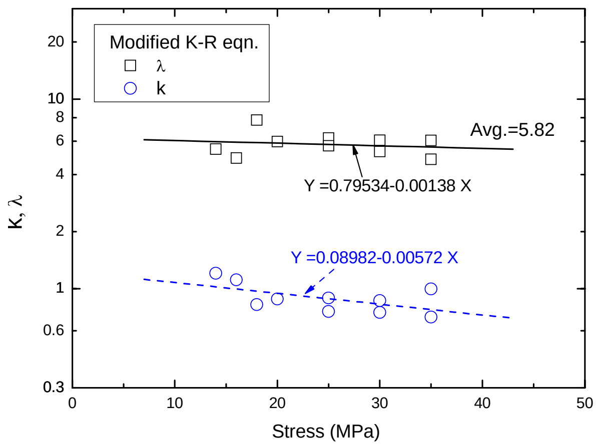

Figure 5. The K and λ variations as a function of the stress by the modified eqn..

3. Conclusion

Nonlinear fitting method can be a useful tool for describing a creep curve. The master curves of the modified K-R model showed better agreement than those of the K-R one. It was found that the λ parameter was not changed as a function of the stress, and the values were 3.9 in the K-R one and 5.82 in the modified one. The modified eqn. can be utilized for describing the creep curve for nickel-based HX alloys.

REFERENCES

[1] W. G. Kim, et al, Mechanical Property and Its Comparison of Superalloys for High Temperature Gas Cooled Reactor, KAERI/AR-723/2005. pp. 1-25, 2005.

[2] K. Maruyama, C. Harada, H. Oikawa, A Strain-Time Equation Applicable up to Tertiary Creep Stage, J. Soc. Mater. Sci., Japan, Vol. 34, pp. 1289-1295, 1985.

[3] W. G. Kim, S. H. kim and W. S. Ryu, Creep Characterization of Type 316LN Stainless Steel and HT-9 Stainless Steels by the K-R Damage Model, KSME International Journal, Vol. 15, No. 11, pp. 1463~1471, 2001.

[4] R. K. Penny, and D. L. Marriott, Design for Creep, Chapman & Hall, pp. 24~26, 1995.

[5] R. K. Penny, The Usefulness of Engineering Damage Parameter during Creep, J. Metals and Materials, Vol. 8, pp. 278-283, 1974.

[6] O. K Lim, T. K. Hwang, and E. H. Choi, A Sequential Approximate Optimization Technique Using the Previous Response Values, Transactions of the KSME, A, Vol.29. No.1, pp.45~52, 2005.