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Model-based Approach for Long-term Creep Curves of Alloy 617 for a High Temperature Gas-cooled Reactor

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1. Introduction

Alloy 617 is a principal candidate alloy for the high temperature gas-cooled reactor (HTGR) components, because of its high creep rupture strength coupled with its good corrosion behavior in simulated HTGR-helium and its sufficient workability [1].

To describe a creep strain-time curve well, various constitutive equations have been proposed by Kachanov-Rabotnov [2], Andrade [3], Garofalo [3,4], Evans [5] and Maruyama [6], et al.. Among them, the K-R model has been used frequently, because a secondary creep resulting from a balance between a softening and a hardening of materials and a tertiary creep resulting from an appearance and acceleration of the internal or external damage processes are adequately considered. In the case of nickel-base alloys, it has been reported that a tertiary creep at a low strain range may be generated, and this tertiary stage may govern the total creep deformation [7]. Therefore, a creep curve for nickel-based Alloy 617 will be predicted appropriately by using the K-R model that can reflect a tertiary creep.

In this paper, the long-term creep curves for Alloy 617 were predicted by using the nonlinear least square fitting (NLSF) method in the K-R model. The modified K-R model was introduced to fit the full creep curves well. The values for the λ and K parameters in the modified K-R model were obtained with stresses.

2. Methods and Results

2.1 NLSF of experimental creep curves

Creep data for the alloy 617 was obtained from the creep tests with different stress levels, 35MPa, 30MPa, 25MPa, 22MPa, 20MPa, and 18MPa at 950°C. Using the short-term experimental creep curves, the long-term creep curves are obtained by the NLSF method in the K-R model.

The K-R eqns. is described, as follows [2],

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

$$\varepsilon^* = \dot{\varepsilon}_o \cdot t_r (= \varepsilon_r / \lambda) \quad (2)$$

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

Fig. 1 shows a typical NLSF result by the K-R model of eqn.1 for the full creep curve at 35MPa. The square symbols indicate the experimental creep curves, and the solid lines indicate the result obtained from the NLSF curve of the K-R eqn.. The NLSF curve between a strain fraction ($\varepsilon/\varepsilon^*$) and a life fraction ($t/t_r$) reveals a poor agreement with R^2=0.97 to the experimental curve. Where, R^2 is a coefficient of determination as a statistic parameter. On the other hand, to obtain a closer match to the experimental creep curves, this study has introduced a modified K-R model, as follows,

$$\frac{\varepsilon}{\varepsilon^*} = K, \lambda \left[1 - \left(1 - \frac{t}{t_r} \right)^{1/\lambda} \right] \quad (3)$$

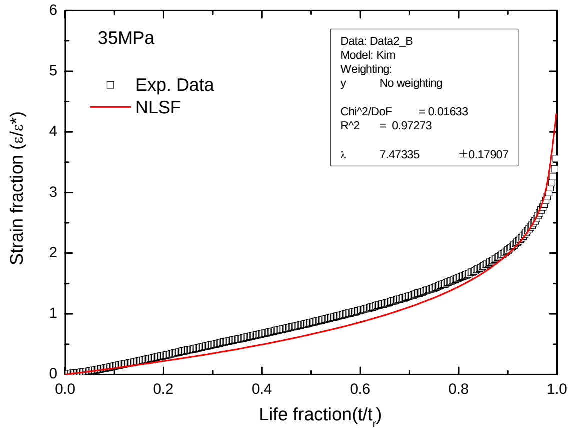

Fig. 1. Strain fraction vs. life fraction curve obtained by NLSF of the K-R equation at 35MPa.

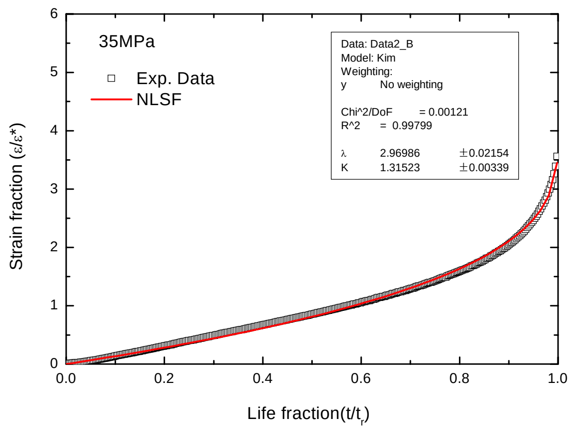

Fig. 2. Strain fraction vs. life fraction curve obtained by NLSF of the modified K-R equation at 35MPa.

Fig. 2 shows a typical NLSF result by the modified K-R model at 35MPa. The NLSF result for the modified one reveals a better agreement with R^2=0.997 to the experimental curves. It is clearly seen that the modified K-R model has a superior agreement to those of the K-R one. In addition, for the average value of the R^2 for all the stress levels, the modified K-R one was higher with 0.988 than 0.963 in the K-R one, as shown in Fig. 3.

Therefore, in this study, the modified K-R model was employed to predict the long-term creep strain time curves. The creep muster curves for each stress level were obtained by the NLSF of the modified K-R model. The average values for λ and K in the modified K-R model were 2.78 and 1.24, respectively. These parameters can be considered as constant parameters regardless of the stress variations, as shown in Fig. 4.

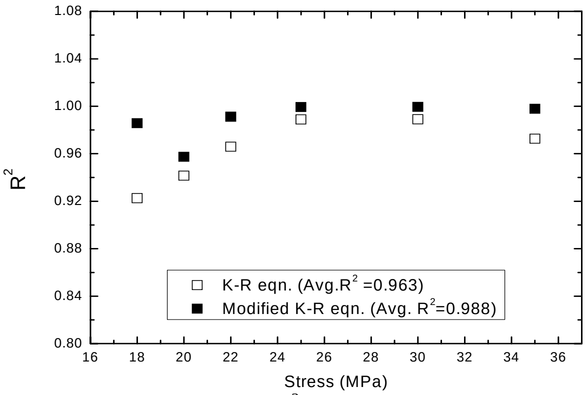

Fig. 3. Comparison of the R^2 values between the K-R and modified K-R models.

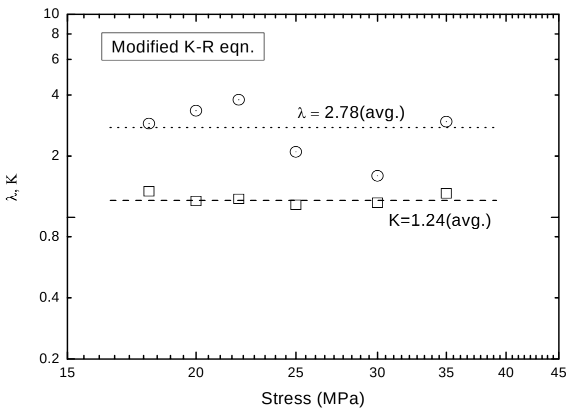

Fig. 4. A stress dependency of the K and λ in the modified K-R model.

2.2 Prediction of the long-term creep curves

To predict the long-term creep curves using the modified K-R eqn. (3), it is necessary to know the K, λ and ε^* values. The K and λ values have already been obtained by the NLSF, as described above, and the M-G strain, ε^* was determined with the stress variations. The ε^* values increased with an increasing stress. From this linear relation, the ε^* value at a given stress level was predicted, and a creep rate at a given stress level was obtained by Norton's law. Then, a long-term rupture time can be predicted by using the M-G relation. Finally, the long-term creep curves at a given rupture time can be modeled mathematically by eqn. (3). The results of the modeled creep curves for up to 500,000 hours are shown in Fig. 5.

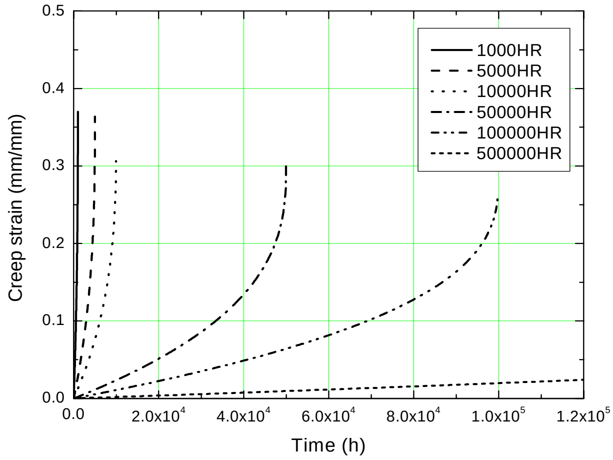

Fig. 5. The long-term creep curves predicted for alloy 617 at 950°C.

3. Conclusions

In the nonlinear fitting of full creep curves for Alloy 617, the K-R model showed a poor match to the experimental curves, but the modified K-R one revealed a good agreement to them. The M-G strain follows the behavior of a stress dependency, but the λ parameter was constant with a stress independency. The λ value in the modified K-R model was 2.78. The long-term creep curves above 10^5 hours from the short-term creep data were successfully predicted by the modified K-R model.

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