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New Methodology to Predict the Long-term Creep Strength of Alloy 617 for a Very High Temperature Reactor

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1. Introduction

Alloy 617 is a prime candidate material for the very high temperature gas-cooed reactor(VHTR) components due to its superior creep resistance above 800°C when compared to other candidate alloys; Haynes 230, Hastelloy-X and Alloy 800 [1]. Considerable creep data for Alloy 617 is available in the literature, and a draft Alloy 617 code case and ASME Boiler and Pressure Vessel (BPV) Code-Section II [2] have also provided allowable stress values for a 10^5 h design period at temperatures up to 982°C. However, the creep and oxidation behaviors for Alloy 617 are not well understood yet, and their long-term creep strength should be predicted for use in a design and analysis.

So far, Larson-Miller (LM) parameter method known as a time-temperature parameter (TTP) has been the most commonly used to predict the long-term creep life from short-term creep data [3]. TTP constant *C* in the LM method is unique for a given set of creep rupture data to be analyzed. Temperature dependency of a rupture life, $d\log t_r / d(1/T)$, should not change in the data set. But, this assumption is not always valid, because the *C* for the rupture life changes from a high value of the short term creep to a low value of the long term creep. So, Maruyama et al. [4] have reported that the multi region analysis for *Q* in Orr-Sherby-Dorn (OSD) parameter could evaluate the long-term rupture of austenite stainless steels and 9-12% Cr steels accurately. However, an overestimation of the long-term rupture in the LM parameter has not been reported for Alloy 617, and furthermore, to avoid it, a multi constant method for the *C* in the LM parameter has not been demonstrated by others.

In this paper, a longer creep life for above 10^5h at 950°C was accurately predicted by using a new method with two *C* values in the LM parameter. Also, oxidation behavior was investigated by using a scanning electron microscope (SEM) and an energy dispersive X-ray spectroscopy (EDX) analysis.

2. Methods and Results

2.1 Creep and oxidation behavior

Alloy 617 (Inconel 617) was a hot-rolled plate with a thickness of 15.875mm (5/8 inch). Creep specimens were a cylindrical form of a 30 mm gauge length and a 6 mm diameter. Creep tests were conducted with different stress levels, 35MPa, 30MPa, 25MPa, 22MPa, 20MPa and 18MPa at 950°C. Creep strain data with elapsed times was taken automatically by a personal computer through an extensometer attached to the creep specimens. Creep curves of Alloy 617 were obtained for different stress stresses at 950°C. Long-time creep curve reaching 14,100h (1.6year) was obtained successfully for 18MPa, as shown in Fig. 1.

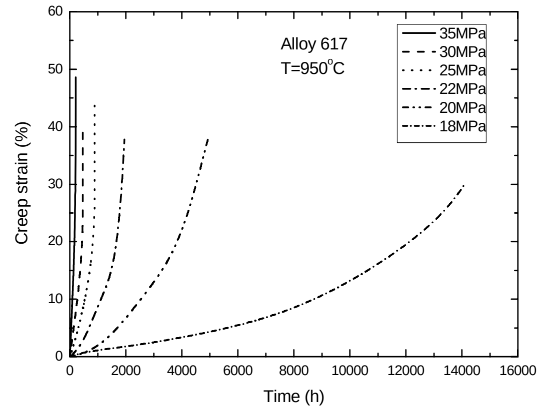
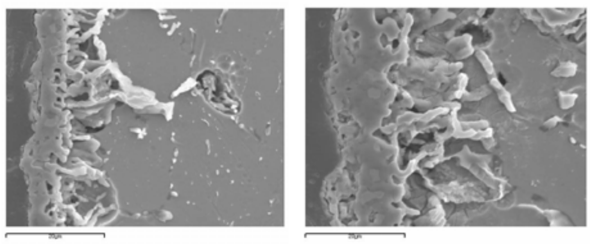


Fig. 1. Creep curves obtained with the elapsed times for different stress levels at 950°C for Alloy 617.



(a) 465h (30MPa @950°C) (b) 4,943h (20MPa @950°C)

Fig. 2. Thickness of the oxide layers for the creep rupture times

Fig. 2 shows Cr_2O_3 layer formed on the surface. A thin internal sub layer consisting of (Cr, Al, Ti) oxide was formed with rod shapes just beneath the Cr_2O_3 layer. And, a thick carbide-depleted zone was developed by a reaction of the chromia and carbide precipitates below the thin internal sub layer. Low stress specimens (long creep-rupture time) formed a heavier oxidation layer and a wider carbide-depleted zone than the high stress ones due to an exposure in air at a high temperature. Photo (a) is for the creep rupture time of 465h (30MPa @950°C) and photo (b) is for 4,943h (20MPa @950°C). It appears that the oxide layer was thicker for the specimen with a longer creep rupture time. The thickness of the Cr-oxide layer was measured from a SEM image. The thickness increased with increasing creep rupture times. This oxide behavior was because Alloy 617 is a chromia-forming alloy on the surface due to an exposure at a high temperature during a creep.

2.2 Prediction of the long-term creep strength

To accurately predict the long-term creep strength, the present works have been performed by using two methods; a conventional method using a unique constant and a new one using two constants for the C in the LM parameter. The basic equation of the LM parameter (P) is given by

$$P = (T + 273.15)\,[\log\,(t_R + C)] \tag{1}$$

where, T is the absolute temperature, C is a constant, and t_R is the rupture time. A stress function of the x-axis can be expressed by a polynomial equation,

$$P = f(\sigma) = b_o + b_1(\log\sigma) + b_2(\log\sigma)^2 + \cdots b_k(\log\sigma)^k \tag{2}$$

where, b_k is the regression coefficient in the k order, and k is the order of the polynomial equation.

In the conventional method using a unique C value in the LM parameter, the optimal value was found to be C = 18. Third-order polynomial equation was obtained from the master rupture curves of the LM parameter versus the stress. Using the polynomial equation for C = 18, the long-term creep strength was predicted for up to 10^6 h from 800°C to 1000°C, as shown in Fig. 3. The predicted curves were not bent for a long period of 10^5 h to 10^6 h and did not thoroughly match with the creep rupture data, and they were overestimated as well.

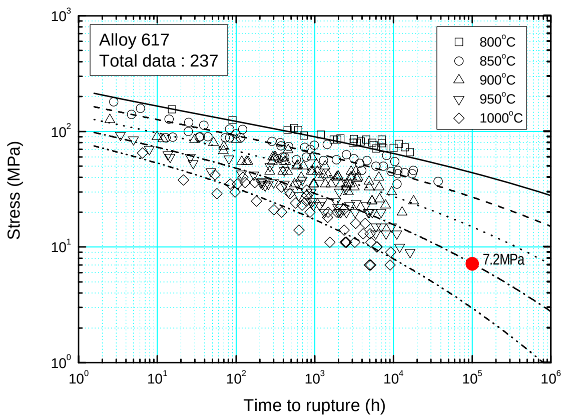


Fig. 3. Creep strength predicted by a unique value of C = 18 at temperatures of 800 to 1000°C of Alloy 617.

For 10^5h at 950°C, the predicted stress was 7.2MPa. This value was almost similar to 7.9 MPa reported in the ASME BPV Code Section II. It is obvious that the allowable stress for 10^5 h for Alloy 617 was overestimated when compared with the experimental creep rupture data. Therefore, both the predicted strength in this study and the allowable stress in ASME should be re-evaluated so as not to be overestimated for a long period above 10^5 h at 950°C.

Fig. 4 shows a comparison of the creep strength curves predicted by the unique C and multi C methods with an application of the LM parameter at 950°C. The unique C method has a higher value in the predicted curve than the multi C one with C=20 and C=10 for 10^5 h and 10^6 h. Thus, this multi-constant method can be used to accurately predict the long-term creep strength of Alloy 617 for VHTR components which will be designed for a design life of 30 to 60 years at 950°C.

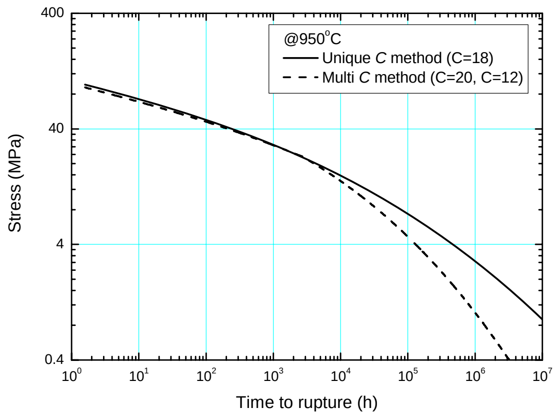


Fig. 4. Comparison of predicted creep strength for the unique C and multi C methods at 950°C.

3. Conclusions

To accurately predict the long-term creep strength of Alloy 617 for above 900°C, a new method with two C values was adopted instead of a conventional one with a unique C value. The conventional method did not thoroughly match with the creep rupture data, and it showed an overestimation for the prediction of the long-term creep strength. On the other hand, the new method revealed a good agreement with the creep rupture data. For 10^5h at 950°C, the strength predicted by new method was lower with 4.7MPa than 7.2MPa by the conventional one.

REFERENCES

[1] S. Dewson and X. Li. Selection Criteria for the High Temperature Reactor Intermediate Heat Exchanger. Proceedings of ICAPP 05, Paper No.5333, Seoul, 2005.
[2] ASME Boiler and Pressure Vessel Code, Section II, Materials Part D-Properties, New York, 2004.
[3] 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, Vols. 297-300, pp. 2272-2277, 2005.
[4] Maruyama K. and Yoshimi K. Methodology of Creep Data Analysis for Advanced High Cr Ferritic Steel. Proceedings of CREEP8, ASME PVP2007-26150, Texas, 2007.