Analysis of an Overestimation of the Long-term Creep Life for Alloy 617

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1. Introduction

Ni-base superalloys are used for high temperature applications such as turbine blades, structural materials for nuclear reactors, and a very high temperature reactor (VHTR) for a hydrogen production. Especially, since the VHTR components such as the hot gas ducts and intermediate heat exchanger (IHX) are operated during a design life of 30 to 60 years at 950°C and 3~8MPa in He impurities [1], their components are required to have a good high temperature strength, creep-rupture strength, high-temperature stability, and a good corrosion resistance. Among them, above all, a long-term creep strength is important, because the integrity of the components should be preserved during a design life of over 30 years at a maximum operating temperature up to 1000°C [2].

Presently, Alloy 617 is known as one of the most suitable materials for the IHX application of a VHTR [1], because this alloy has a superior creep strength at a high temperature above 900°C to other candidate alloys; Haynes 230, Hastelloy-X, Alloy 800. To predict a long-term creep rupture life from short-term creep data, a Larson-Miller (L-M) parameter in the time-temperature parameter (TTP) methods has been typically used. However, a constant *C* value including an apparent activation energy *Q* in the L-M equation, sometimes cause a change from a high value of a short term creep to a low value of a long term creep. The L-M analyses ignore the decrease in the constant *C,* as a result, the creep rupture life is overestimated. Thus, to accurately predict a long-term creep life or creep stress at a given time, an effect on the constant *C* should be verified.

In this paper, to accurately predict a long-term creep stress or life for Alloy 617, lots of creep rupture data was collected through world-wide literature surveys. Using these data, the *C* values in the L-M equation were determined for each temperature range; 800, 850, 900, 950 and 1000°C. Also an optimal *C* value was found by a regression of a creep master curve. A long-term creep life for the various *C* values was predicted up to 10^6 hours. The predicted stress at a high temperature above 950°C is discussed for its effect of the *C* values.

2. Methods and Results

2.1 Overestimation of Larson-Miller Parameter

The L-M parameter, as well known TTP method, has been typically used to estimate creep rupture life of various steels. The L-M equation can be written by

$$P(t_r, T) = T\left[\log_{10}(t_r + C\right] = Q/2.3R \qquad (1)$$

where, T is the absolute temperature (K), t_r is an experimental rupture time, Q is the activation energy [kJ/mol], R is the gas constant [8.314 J /K · mol] and C is a constant. As seen in Eq. (1), the L-M method is based on a crucial assumption that the TTP constant, such as Q and C is unique for a given set of creep rupture data to be analyzed. Namely, temperature dependence of rupture life, $d\ln/d(1/T)$, should not change in the data set. However, actually, this assumption is not always valid. Maruyama et al. [3] have pointed out that a change in $d\ln/d(1/T)$ is the major cause of the overestimation, and they have proposed a multi regression analysis of creep rupture data. In the L-M parameter, the C value changes from a high value of a short term creep to low value of long term creep, and also changes with test temperature or stress levels in creep. The L-M analyses ignore a decrease in the constant C, and predicts with only unique value by coupling different temperatures. As the result, the long-term creep rupture life or stress is overestimated.

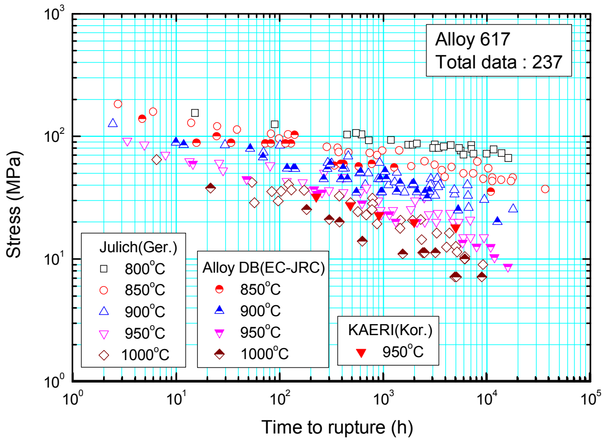

Figure 1. Creep rupture data collected for 800 to 1000°C of Alloy 617

2.2 Long-term Life Prediction for Alloy 617

To predict a long-term creep life for Alloy 617, lots of creep rupture data through Alloy-DB of EC-JRC (licensed CD) [4] and literature surveys; the data of Schubert et al. of Julich Institute in Germany [5] and the data of KAERI were collected for 800°C to 1000°C, as shown in Fig.1. The optimal value of C = 18 was determined by the best fit of the master rupture curve, which is to plot between a stress and the L-M parameter. This value was determined reasonably by using coefficient of determination, R_2, which is a statistical parameter, as shown in Figs. 2 and 3. Using the C = 18 value, a creep rupture life was predicted up to 10^6 hours, as shown in Fig. 4. However, the predicted curves were not bent for 10^5 to 10^6 hours at 950°C and 1000°C and overestimated for a stress value. For 950°C, as shown typically in Fig. 5, the C value shows a high value of C = 26 for a short-term creep life, and a low value of C =10 for a long-term creep life.

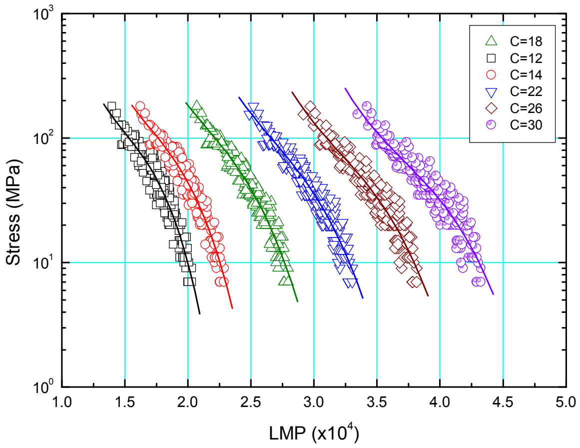

Figure 2. Master rupture curves with different C values for the whole creep data of Alloy 617

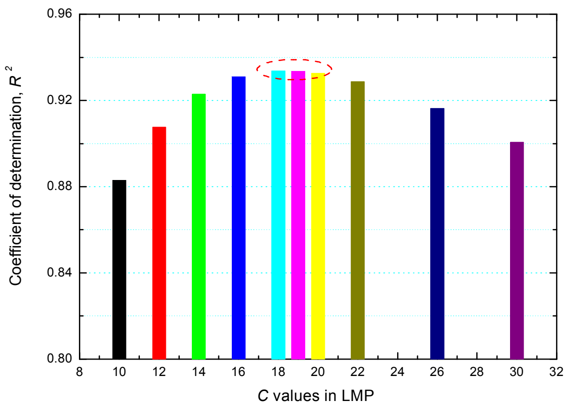

Figure 3. Variations of coefficient of determination with the C values of master rupture curve

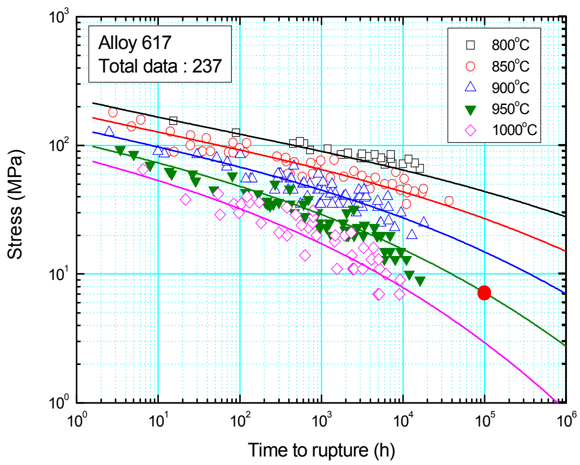

Figure 4. Creep life prediction at C = 18 for 800 to 1000°C of Alloy 617

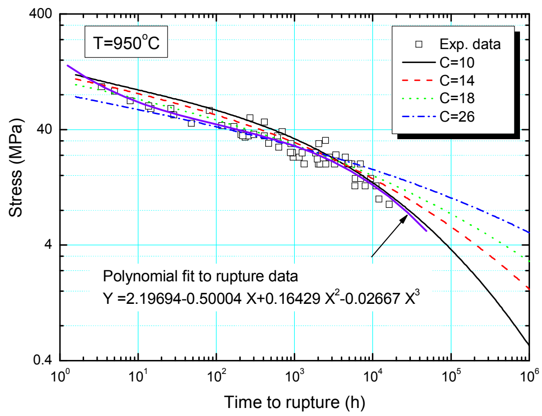

Figure 5. Long-term life prediction with different C values at 950°C of Alloy 617

Therefore, to accurately predict a creep life or stress at 950°C and 1000°C, a unique C value is not proper, and multi C values are proper. From this result, it is also identified that the C values depend on both a temperature and a stress by calculating for different temperature ranges using the data of Fig. 1.

3. Conclusion

To predict accurately a long-term creep life or stress for Alloy 617, the master rupture curves were obtained for various C values, and an optimal value of C = 18 was determined by using the coefficient of determination. However, the predicted curve by C = 18 were not bent for 10^5 to 10^6 hours at 950°C and 1000°C, and overestimated in a stress value. To accurately predict the long-term creep life at a temperature above 950°C, a single curve having a unique C value was not proper, and multi curves having different C values were proper. It is also identified that the C values in the L-M equation depend on both a temperature and a stress in a creep.

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