Creep-Data Analysis of Alloy 617 for High Temperature Reactor Intermediate Heat Exchanger

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1. Introduction

The design of the metallic components such as hot gas ducts, intermediate heat exchanger (IHX) tube, and steam reformer tubes of very high temperature reactor (VHTR) is principally determined by the creep properties, because an integrity of the components should be preserved during a design life over 30 year life at the maximum operating temperature up to 1000°C [1]. For designing the time-dependent creep of the components, a material database is needed, and an allowable design stress at temperature should be determined by using the material database.

Alloy 617, a nicked based superalloy with chromium, molybdenum and cobalt additions, is considered as a prospective candidate material for the IHX because it has the highest design temperature [2]. The alloy 617 is approved to 982°C (1800°F) and other alloys approved to 898°C (1650°C), such as alloy 556, alloy 230, alloy HX, alloy 800. Also, the alloy 617 exhibits the highest level of creep strength at high temperatures. Therefore, it is needed to collect the creep data for the alloy 617 and the creep-rupture life at the given conditions of temperature and stress should be predicted for the IHX construction.

In this paper, the creep data for the alloy 617 was collected through literature survey. Using the collected data, the creep life for the alloy 617 was predicted based on the Larson-Miller parameter. Creep master curves with standard deviations were presented for a safety design, and failure probability for the alloy 617 was obtained with a time coefficient.

2. Methods and Results

2.1 Creep-life prediction for alloy 617

Figure 1 is the results of all the creep rupture data collected from European Alloy-DB [3], Schubert et al. [4] and ANL (Argone National Laboratory) [5] reports for alloy 617. It was investigated that the creep rupture time with different product forms such as plate, rod and sheet exhibits almost identical value. So, all the creep-rupture data was presented together regardless of the product forms as shown in Figure 1. Using this creep-rupture data, a long-term creep lifetime up to 10^6 hour was predicted using the equation of the Larson-Miller (L-M) parameter (P) as follows;

$$P = (T + 273.15)\left[\log_{10}(\alpha_R \cdot t_R + C\right] . \qquad (1)$$

Where, T is absolute temperature (K), C is a constant, α_R is a time coefficient, and t_R is creep-rupture time. In this study, the C value was applied with 20. A creep stress was obtained as a function of P, as shown in Figure 2. The second-order polynomial equation was obtained from the best fitting of all the creep data. Creep master curves for the alloy 617 were obtained in the standard deviation of 1σ, 2σ and 3σ.

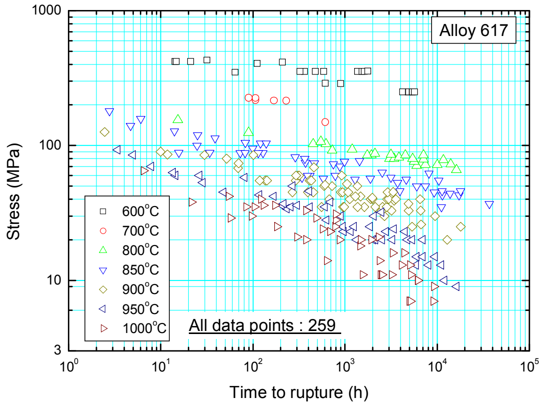

Figure 1. Creep rupture data collected for Alloy 617

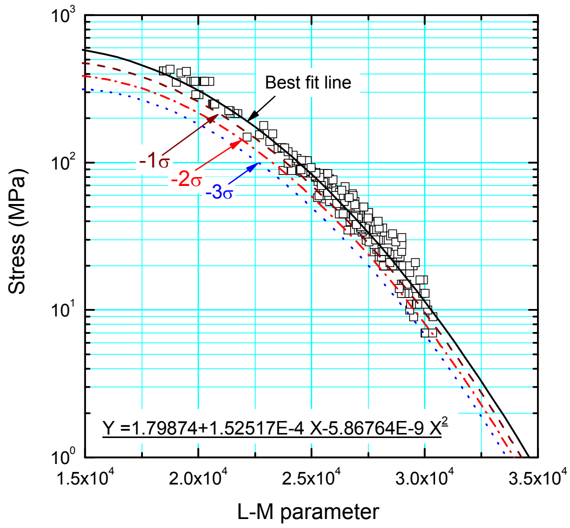

Figure 2. Creep stress with the L-M parameter in the standard deviation of 1σ, 2σ and 3σ

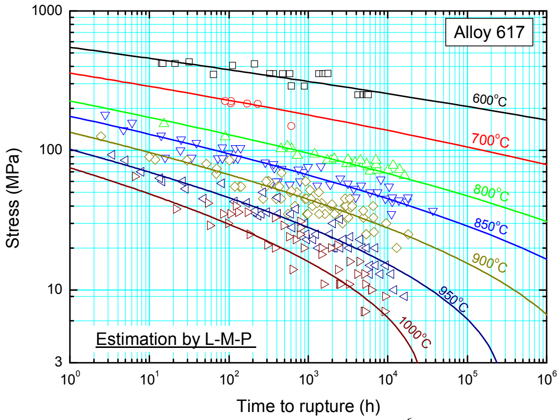

Figure 3. Creep-life prediction up to 10^6 hour by the L-M parameter with different temperatures of Alloy 617

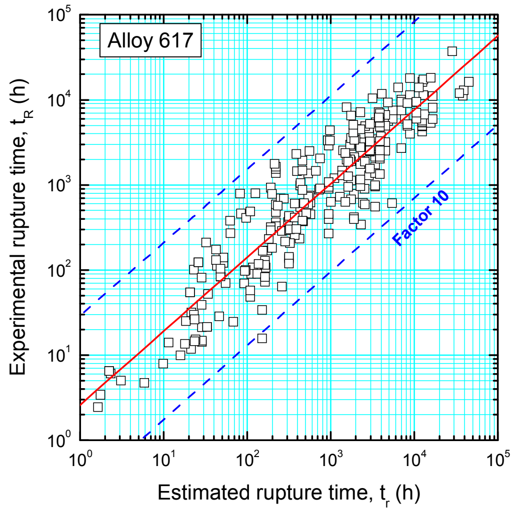

Figure 4. Correlation between experimental rupture time and estimated rupture time

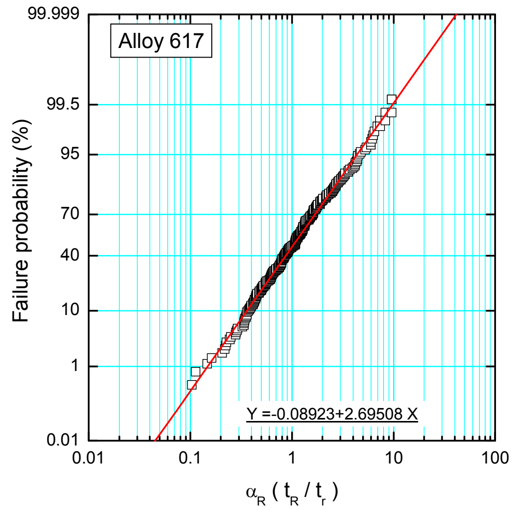

Figure 5. Failure probability with a time coefficient

Figure 3 shows the results of the creep-life prediction based on the L-M parameter with different temperatures for alloy 617. The creep lifetime can be predicted up to 10^6 hour. Correlation between the experimental rupture time (t_R) and estimated rupture time (t_r) obtained by the L-M parameter was close as shown in Figure 4. It is found that all the creep data points were well included within factor 10. Thus, it is suggested that a safety design on the creep rupture time can be applied with factor 10.

2.2 Failure probability

Figure 5 shows the result of failure probability as a function of the time coefficient, α_R (= t_R / t_r). Correlation between failure probability and time coefficient was very close. Creep rupture data followed well the lognormal distribution with a good linearity. Using this result, the failure probability for an individual data set can be estimated probabilistically for the alloy 617.

3. Conclusion

To design a high-temperature creep for the alloy 617, the creep rupture data was collected through the European Alloy-DB and available literature surveys. All the creep data conformed favorably together regardless of different product forms of plate, sheet and rod. Creep master curves based on the Larson-Miller parameter were obtained in the standard deviations of 1σ, 2σ and 3σ. Creep lifetime up to 10^6 hour was predicted with different temperatures for the alloy 617. Creep rupture data was conformed to the lognormal distribution, and failure probability for an individual data set was estimated with a time coefficient.

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