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# Analysis of Creep Rupture Data of Alloy 617 for VHTR Application

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## 1. Introduction

A very high temperature reactor (VHTR) is one of the most promising Gen-IV reactors for the economic production of electricity and hydrogen. Its major components are the reactor internals, reactor pressure vessel (RPV), hot gas ducts (HGD), and intermediate heat exchangers (IHX). Since the VHTR components are designed to be used for a 60 year lifetime at a high temperature, the creep behavior is very important for the design application due to creep damage during the long service life at elevated temperatures [1-2]. Alloy 617 is a candidate IHX structural material because of its high-temperature creep properties. However, the ASME design code for Alloy 617 was not developed for design use. Therefore, material works to complete the ASME Alloy 617 code case development are ongoing according to a next-generation nuclear plant (NGNP) research and development plan. Through this plan, a new Alloy 617 Code Case is planned to be approved by 2015.

In this study, the creep rupture data of Alloy 617, which were produced through a series of creep tests at 850-950°C at the Korea Atomic Energy Research Institute (KAERI), were analyzed using various creep laws, and the material constants were obtained and discussed.

## 2. Methods and Results

### *2.1 Creep tests*

A commercial-grade nickel-based superalloy, Alloy 617 (Inconel 617) of a hot-rolled plate with a thickness of 15.875mm (5/8 inch) was used for this study. The creep specimens were a cylindrical type with a 30 mm gauge length and 6 mm diameter. A constant-load creep machine was used with a lever ratio of 20:1. Creep tests were conducted under different applied stress levels at temperature ranges of 850-950°C in dry air. The temperature during the creep tests was measured using K-type thermocouple attached to the specimens, and was maintained within ±2°C. Creep strain data with elapsed times were taken automatically by a PC through an extensometer attached to the creep specimens. Creep curves with variations were obtained, and the value of the creep strain rate was obtained by calculating the secondary creep stage from the strain–time creep curves.

### *2.2 Analysis of creep rupture data*

The creep rupture data for Alloy 617 such as the rupture time, creep strain rate, rupture elongation and reduction of the area were obtained at 850-950°C. These property data were analyzed using the plots of various creep laws such as Norton's power law, Monkman-Grant Relation (MGR), Modified Monkman-Grant Relation (MMGR), and Zener-Hollomon Parameter (ZHP). In addition, the material constants in these creep laws are given here.

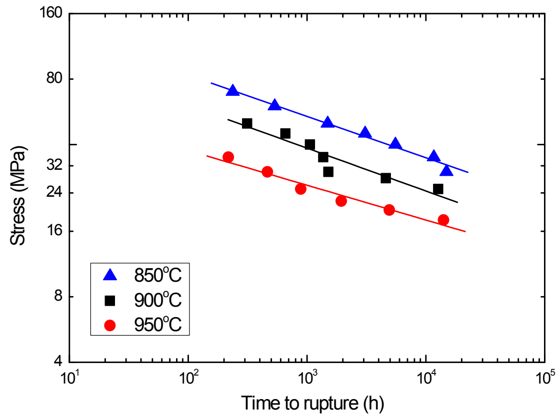


Fig. 1. Plot of stress vs. time to rupture of Alloy 617 tested at 850 °C, 900 °C, and 950°C.

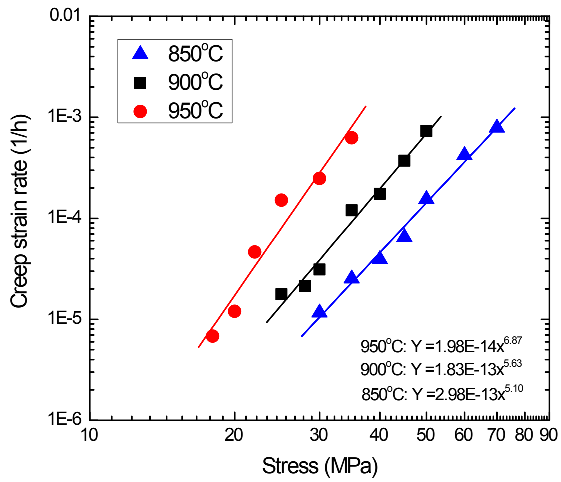


Fig. 2. Plot of Norton's power law of Alloy 617 tested at 850 °C, 900 °C, and 950°C.

Fig. 1 shows the plot of log stress vs. log time to rupture of Alloy 617 tested at 850 °C, 900 °C, and 950°C. It is clear that there is a temperature effect in the creep stress with rupture times. In the Plot of Norton's power law of $\dot{\varepsilon}_s = A\sigma^n$, it shows clearly a temperature effect. The slope is n ≅ 5-6, as shown in Fig. 2.

Figs. 3 and 4 show the plots of the Monkman-Grant Relation (MGR), $\log t_r + m \log = C_{MG}$ and Modified MGR, $\log(t_r/\varepsilon_f) + m \log \dot{\varepsilon}_s = C_{MMG}$ of Alloy 617. In the plot of MGR, the data show some scattering at the three temperatures, and the slope on average is m=0.88. On the other hand, the MMGR reduced the data scattering, and it was fitted well with a straight line of m=0.97 regardless of the temperatures. The MMGR is superior in creep data plots to the MGR.

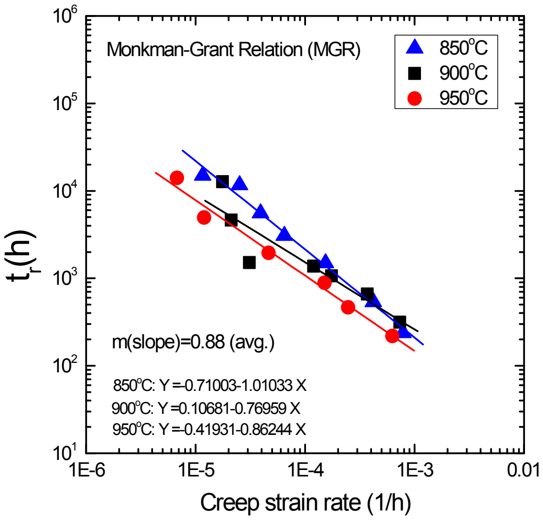


Fig. 3. Plot of the MGR of the tested data at 850- 950°C.

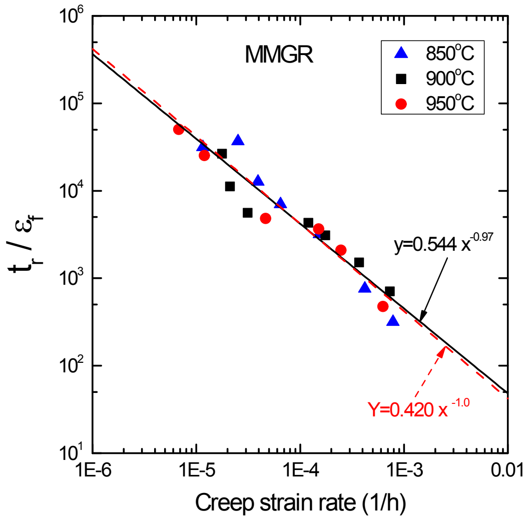


Fig. 4. Plot of the MMGR of the tested data at 850-950°C.

Fig. 5 shows a plot of the Zener-Holloman Parameter as a function of stress (σ/E) of Alloy 617 tested at 850-950°C. The creep strain rate is expressed as [3]

$$\dot{\varepsilon}_s = A_1 \sigma^{n'} \exp(-Q/RT) \quad (1)$$

$$Z = \dot{\varepsilon}_s \exp(Q/RT) \quad (2)$$

where $Q$ is the activation energy, $A_1$ and $n'$ are the experimentally determined constants, and quantity Z is called the Zener-Hollomon parameter. A straight line can be seen well with a slope of n'=5.87 regardless of the three different temperatures. It can be inferred that the same mechanism is operative in the temperature range of the current study.

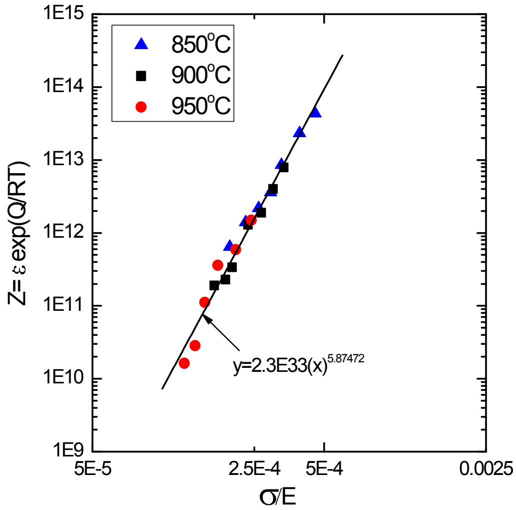


Fig. 5. Plot of the Zener-Holloman Parameter as a function stress (σ/E) of Alloy 617 tested at 850-950°C.

## 3. Conclusions

Creep rupture data of Alloy 617 tested at 850-950°C were analyzed using various creep laws, and material constants were obtained. The MMGR reduced the data scattering, and was well fitted for straight line of m ≅ 1.0 as m=0.97. The MMGR showed a better plot than the MGR. In the plot of ZHP and stress, a straight line was for n'=5.87 regardless of the three different temperatures. Thus, it can be inferred that the same creep mechanism was operative within the current temperature ranges.

## Acknowledgements

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## REFERENCES

[1] W.G. Kim, S.N. Yin, G.G. Lee, Y.W. Kim and S.J. Kim, Creep Oxidation Behavior and Creep Strength Prediction for Alloy 617, Int. J. of Pressure Vessels and Piping, Vol. 87, pp. 289~295, 2010.

[2] J.H. Chang, et al., A Study of a Nuclear Hydrogen Production Demonstration Plant, Nuclear Eng. and Tech., Vol. 39, No.2, pp. 111~122, 2007.

[3] G.E. Deter, and D. Bacon, Mechanical Metallurgy, McGraw-Hill Book Co. pp. 306~307, 1988.