Transactions of the Korean Nuclear Society Spring Meeting
Taeback, Korea, May 26-27, 2011

Creep Properties of Alloy 617 in Air and Helium Environments at 900°C

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1. Introduction

A very high temperature gas reactor (VHTR) is one of the Gen-IV reactors which aim at the safe, long-lived, proliferation-resistant and economical nuclear power plants. Its high operating temperature of over 800° C enables high energy efficiency and the production of hydrogen gas using Sulfur-Iodine process. The heat of the primary helium (He) circuit transfers to the secondary helium loop through the intermediate heat exchanger (IHX). The IHX component needs high-temperature creep resistance in the He environment, and also it requires good oxidation resistance, corrosion resistance, and phase stability at high temperatures [1-4].

Currently, Alloy 617 is a prime candidate material because of its excellent mechanical properties at high temperature [5]. Its superiority originates from solid-solution strengthening by various additional components such as Co and Mo. Some researchers reported that the creep rupture time varied widely at high-temperature He environments. However, it has not been well established that the test temperature and minor impure gases in the He drastically affected the rupture time. Also, the creep data for Alloy 617 in the He environment are still insufficient for design application, and it is not yet well understood enough about the creep mechanism of the He effect.

In this study, to provide creep data for Alloy 617 in the air and He environments, a series of creep tests was conducted with different applied stress levels at 900°C. Their creep properties were investigated and were compared.

2. Methods and Results

2.1 Experimental procedures

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. Creep specimens in air and He environments were a cylindrical form of a 30 mm gauge length and a 6 mm diameter. Creep tests were conducted under different applied stress levels, 50MPa, 45MPa, 40MPa, 35MPa, 32MPa, 30MPa, 28MPa and 25MPa at 900°C. Creep strain data with elapsed times was taken automatically by a personal computer through an extensometer attached to the creep specimens. Creep curves with variations were obtained, and the value of a minimum creep rate was obtained by calculating the secondary creep stage from the strain–time creep curves.

Before the creep tests, a vacuum chamber made for the quartz tube was purged with three or four times by a vacuum pump to remove some impurities in the chamber. During the creep tests, pure He with 99.9995% was supplied on the creep specimens attached in the quartz tube. Impurity concentration in pure He gas was O_2 < 1.0, N_2 < 5.0 and H_2O < 1.0. Flow rate of the He gas was controlled under 20 cm^3/min.

2.2 Creep properties in air and He environments

The creep rupture data such as the rupture time, minimum creep rate, rupture elongation and reduction of area were obtained for Alloy 617 in the air and He environments at 900°C. Their creep properties were compared, respectively.

It appeared that there were no large differences in the shapes of the creep curves between the air and He environments. They revealed little primary creep strain, and a secondary creep stage was clearly observed at this temperature condition at the low stress level (25MPa in air). The secondary creep stage was not clearly observed at 950°C. However, at 900°C, the creep curve showed the secondary creep region of two steps. Thus, it is believed that there was a little difference in the secondary creep curves between 950°C and 900°C. Also, the onset of a tertiary creep was unclear, and a sufficient ductility (>30%) was achieved in spite of the long duration of about 13,100h.

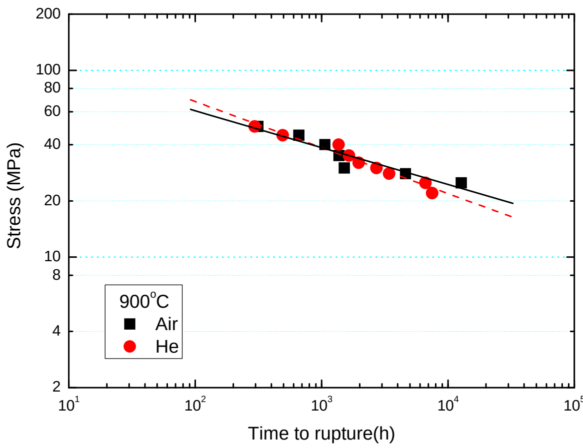

Fig. 1. Comparison of the log stress vs. log time to rupture in air and He environments at 950°C

Fig. 1 shows the comparison result of the log stress vs. log time to rupture in air and He environments at 900°C. For high stress range above about 30MPa, rupture time between air and He environments was almost similar. But, for low stress range below about 30MPa, rupture time in air was longer than that in He environment. This reason was closely attributed to oxide layer thickness formed during creep time.

In addition, the relationship between a steady state creep rate and stress showed a good linearity in air and He environments. Alloy 617 followed well Norton's power rule at this creep condition. The creep rate in He environment was higher than that in air. Thus, the creep rupture time in the He environment was shorter than that in air.

Fig. 2 shows the comparison result of the Monkman-Grant (M-G) relationship between the creep rupture time and minimum creep rate. At the identical creep rate, the creep rupture time in air was longer than that in He environment.

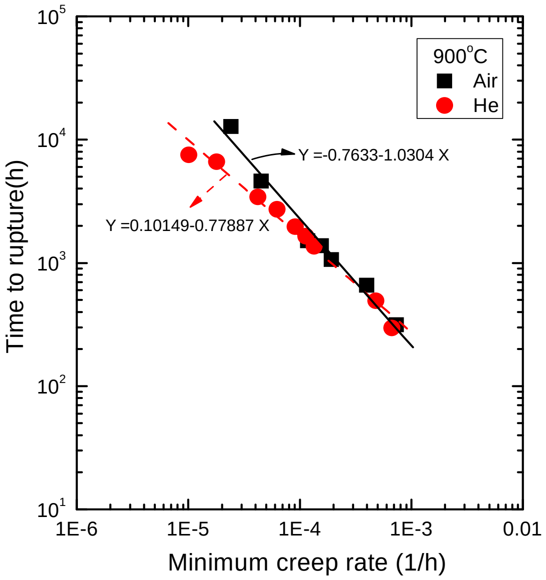

Fig. 2. Comparison of Monkman-Grant(M-G) relationship in air and He environments at 900°C

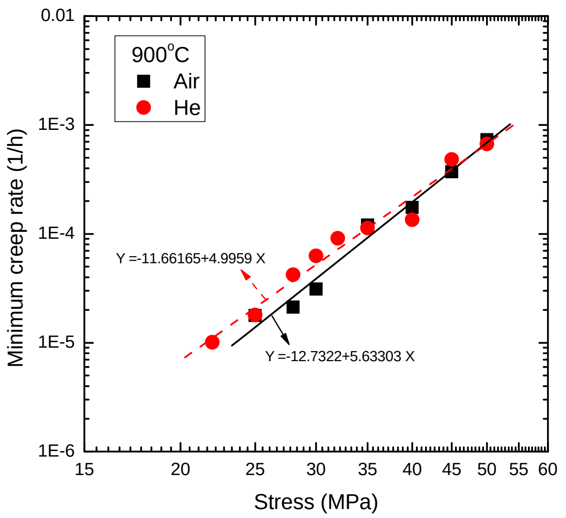

Fig. 3. Minimum creep rate vs. stress of Alloy 617 in the air and He environments at 900°C

Fig. 3 shows the power-law relationships between a minimum creep rate and stress. At this creep condition for Alloy 617, since creep deformation corresponds to power-law creep region, the mechanism of creep deformation is governed by a climb of dislocation. Thus, the relationships showed a good linearity. The constants of Norton's power law, $\dot{\varepsilon}_m = A\sigma^n$ could be determined. In the He environment, the *A* value was 1.86×10^{-13} (MPa^{-n} h^{-1}), and the *n* value was 5.0. Also, in air, the *A* value was 2.19×10^{-12} (MPa^{-n} h^{-1}), and the *n* value was 5.63. Thus, it was identified that the minimum creep rate in the He was a little faster than that in the air.

In addition, we investigated creep ductility. It appeared that, as the stress decreased down to 30MPa, the creep ductility decreased significantly. But, at lower stress ranges, the creep ductility increased slightly with stress variations.

3. Conclusions

Alloy 617 followed Norton's power law and the Monkman-Grant relationship well. It appeared that there were no large differences in the shapes of the creep curves between the air and He environments. The minimum creep rate in the He environment was a little faster than that in the air. The time to rupture in the He environment was shorter than that in the air. As the stress decreased, the creep ductility decreased significantly. But, at lower stress level, the ductility increased slightly with stress variations.

Acknowledgements

This study was supported by the Korean Ministry of Education, Science & Technology through its National Nuclear Technology Program.

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