Creep Behaviors of Alloy 617 in Air and Helium Environments at 950°C

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1. Introduction

A very high temperature gas-cooled reactor (VHTR) is currently the most promising reactor type among the Generation-IV reactors for producing electricity and hydrogen economically. The VHTR structural components like the reactor internals, piping, hot gas ducts, and intermediate heat exchangers (IHX) are designed for a design life of 60 years at 950°C and 3~8MPa in helium (He) impurities. Their components are required to have good creep properties, oxidation resistance, corrosion resistance, and phase stability at high temperatures. Among them, creep behaviour is one of the most important properties, because the integrity of the components should be preserved during a prolonged period in a VHTR coolant [1-4].

Alloy 617 is a prime candidate material for the VHTR components due to its superior creep resistance above 800°C when compared to other candidate alloys. 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 have also provided allowable stress values for a 10^5 h design period at temperatures up to 982°C [5]. However, creep behaviors for Alloy 617 in He environments have not been well understood yet.

In this paper, creep behaviors were investigated in air and He environments at 950°C and their properties were compared and discussed. Crept microstructures were analyzed by observing SEM images.

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. Their creep tests were conducted under the identical conditions with applied stresses, 35MPa, 30MPa, 25MPa, 22MPa, 20MPa and 18MPa at 950°C, respectively. 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. A steady state creep rate was obtained from the strain–time creep curves.

Before the creep tests, a vacuum chamber made for the quartz tube was purged with three or 4 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 Comparison of creep behaviors in air and He environment

Fig. 1 shows the results of creep curves obtained with the elapsed times for different stress levels in He environment at 950°C. Alloy 617 showed little primary creep strain, and a well-defined secondary creep stage was not observed. The onset of a tertiary creep was unclear, and a tertiary creep stage was initiated from a low strain level. Alloy 617 revealed a good ductility in spite of long duration. It appeared that the shapes of the creep curves in He environments were almost similar.

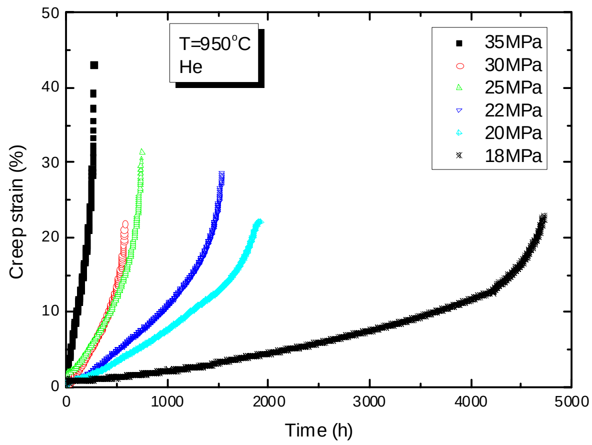

Fig. 1. Creep curves obtained with the elapsed times for different stress levels at 950°C for Alloy 617.

Fig. 2 shows the comparison result of the log stress vs. log time to rupture in air and He environments at 950°C. For high stress region above about 30MPa, time to rupture in He environment was longer than that in air. However, for the low stress region, time to rupture 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. 3 shows the comparison result of the Monkman-Grant (M-G) relationship between the creep rupture time and steady state creep rate. At the identical creep rate, the creep rupture time in air was longer than that in He environment.

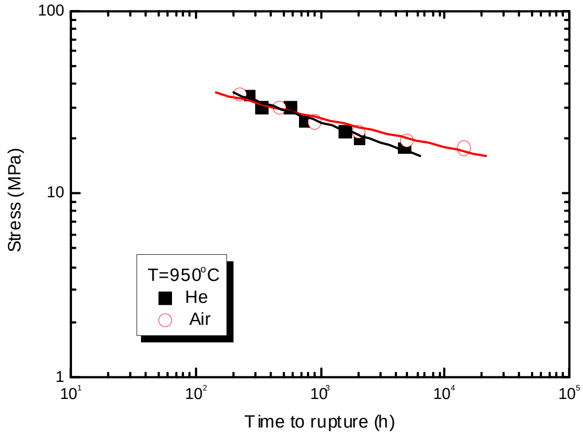

Fig. 2. Comparison of the log stress vs. log time to rupture in air and He environments at 950^{o}C

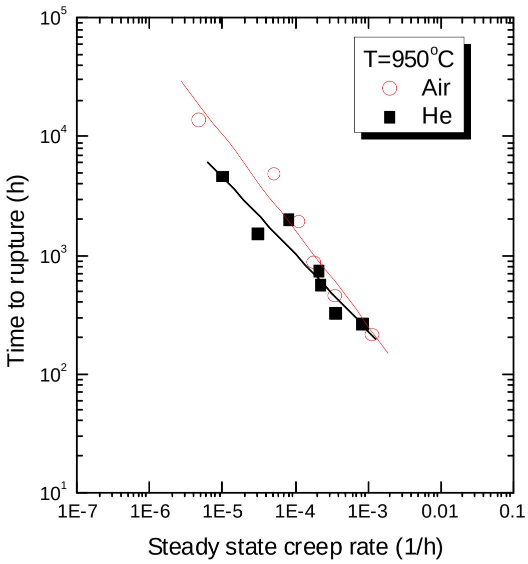

Fig. 3. Comparison of Monkman-Grant(M-G) relationship in air and He environments at 950^{o}C

Fig. 4 shows a SEM image for the oxide layers of the crept specimens with applied stress levels of 35MPa, 30MPa 25MPa 22MPa and 20MPa in air and He environments at 950^{o}C. Both in air and He environment, a Cr_2O_3 layer was formed on outer surface. The oxide layer was thicker for the specimen with a longer creep rupture time in air and He environment. 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. The thickness increased with increasing creep rupture time. However, the thickness of Cr-oxide layer in He environment was more significant with increasing creep rupture time than that in air one. This oxide behavior is because Alloy 617 is a chromia-forming alloy on the surface due to an exposure at a high temperature during a creep.

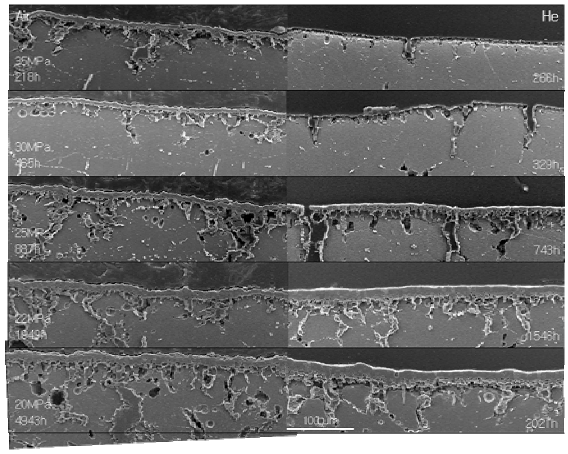

Fig. 4 Oxide layer formed outer surface surface in air and He environments at 950^{o}C

3. Conclusions

Creep behaviors for Alloy 617 for air and He environments at 950^{o}C were comparatively investigated. Creep rupture time in air was longer than that in He environment. Relationships 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, and the creep rupture time in He environment was shorter than that in air. In addition, the thickness of Cr-oxide layer in He environment was more significant with increasing creep rupture time than that in air one.

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