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Creep and Oxidation Behaviors of Alloy 617 in Air and Helium Environments at 1173 K

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Abstract

Creep and oxidation behaviours of Alloy 617 in air and helium (He) environments at 1173K were comparatively investigated under different applied stress levels. There were no large differences in the shapes of the creep curves between the air and He environments. Creep rupture time in the He environment was shorter than that in air. The outer Cr-oxide thickness of the air specimens was thicker in short-tested duration than that of the He specimens. However, in the long-tested duration over 3,000h, the Cr-oxide thickness in the He environment was larger than in air. It was found that creep rupture life was closely related to the thickness of the outer Cr-oxide layer, because the form of the outer Cr-rich oxide layer brings about the Cr-depleted region which may deteriorate material strength or creep life.

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Keywords: Alloy 617; creep; helium; oxidation; oxide layer

1. Introduction

A very high temperature gas reactor (VHTR) is one of the Gen-IV reactors aiming at the safe, long-lived, proliferation-resistant and economical nuclear power plants. Its high operating temperature of over 1073K 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 considered as a prime candidate material because of its excellent mechanical properties at high temperature. Its superiority originates from solid-solution strengthening by various elements such as Co and Mo. Some researchers reported that the creep rupture time varied widely in high-temperature He environments [5-7]. However, it has not been well established that the test temperature and minor impure gases in He environment drastically affected the rupture time. Also, the creep data for Alloy 617 in He

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environment are still insufficient for design application, and the creep and oxidation behaviours are not yet well understood related to the He effect.

In this study, creep rupture data for Alloy 617 in air and He environments were obtained through a series of creep tests conducted with different applied stress levels at 1173K. The creep and oxidation behaviours were comparatively investigated in air and He environments.

2. Experimental procedures

Commercial grade nickel-based superalloy, Alloy 617 (Inconel 617) was used for this study, which was a hot-rolled plate with a thickness of 15.875 mm. Chemical composition of the alloy is given in Table 1. Creep specimens in the air and He environments were the same as cylindrical form of 30 mm gauge length and 6 mm diameter. Creep tests were conducted with different stress levels, 50 MPa, 45 MPa, 40 MPa, 35 MPa, 32 MPa, 30 MPa, 28 MPa, 25 MPa and 22 MPa at 1173 K.

The pull rod and jig used for creep tests were manufactured with Ni-base superalloy materials to endure oxidation and thermal degradation sufficiently during creep. Before the creep tests, a vacuum chamber made for the quartz tube was purged three or four times by a vacuum pump to remove some impurities in the chamber. During the creep tests, He gas with 99.999% purity, such as $H_2O < 1.0$ ppm, $O_2 < 1.0$ ppm, $N_2 < 5.0$ ppm, was supplied on the creep specimens attached in the quartz tube. Flow rate of the He gas was controlled under $20 \text{ cm}^3/\text{min}$. Creep strain data with elapsed times were taken automatically by a PC through an extensometer attached to the creep specimens.

Table 1. Chemical composition of Alloy 617.

Element	Ni	C	Fe	Si	Mn	Co	Cr	Ti	P	S	Mo	Al	B	Cu
Wt. %	Bal.	0.08	1.49	0.06	0.11	11.58	22.16	0.35	0.003	0.001	9.8	1.12	0.002	0.08

3. Results and discussion

3.1. Creep behavior in air and He environments

Figure 1 shows the creep curves obtained for different stresses at 1173 K of Alloy 617. 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. There were no large differences in the shapes of the creep curves between the air and He environments. Alloy 617 revealed sufficient ductility ($>30\%$) in spite of the creep duration of 12,730 h.

Figure 2 shows the variation of log stress vs. log time to rupture in air and He environments at 1173K. For high stress range above about 30MPa, creep rupture time in air and He environments was almost similar. However, for low stress range below about 30MPa, creep rupture time in air was longer than that in He environment. The reason for this is closely related to oxide layer thickness formed during creep time, as discussed in section 3.2. Alloy 617 followed Norton's power rule at this creep condition, because creep deformation corresponds to power-law creep region, the mechanism of creep deformation is governed by a climb of dislocation [4]. Thus, the relationship between a minimum creep rate and stress showed a good linearity in the air and He environments. The creep rate in the He environment was higher than that in the air, as shown in Fig. 3.

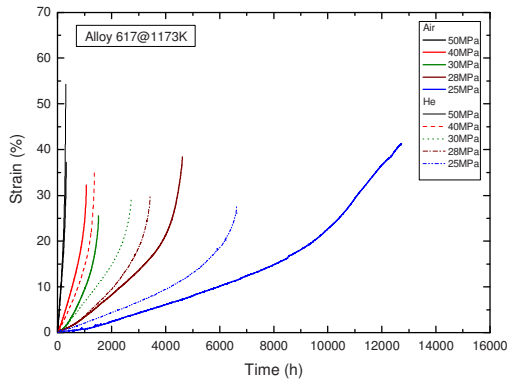


Fig. 1. Creep curves obtained at 1173K.

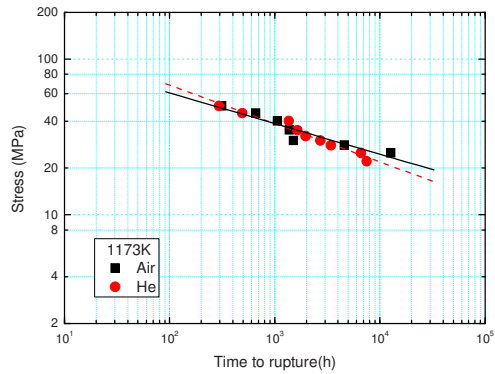


Fig. 2. Log-log plot of stress versus rupture time.

Figure 4 shows the comparison result of the Monkman-Grant (M-G) relationship between the creep rupture time and minimum creep rate in air and He environments. In the M-G relationship, $\log t_r + m\dot{\epsilon}_m = C$, the values of the slope, m were obtained, and were $m=1.03$ in air and $m=0.78$ in He environment. At a given creep rate, the creep rupture time in air was longer than that in He environment.

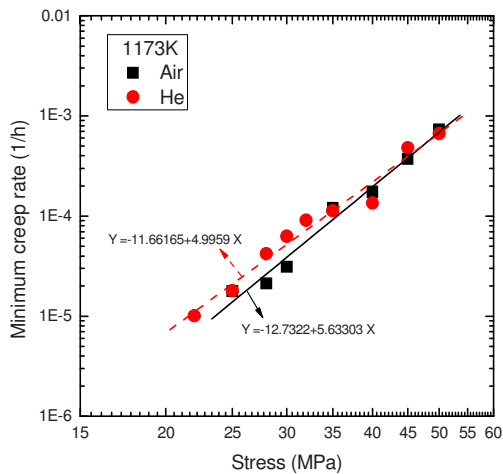


Fig. 3. Minimum creep rate versus stress.

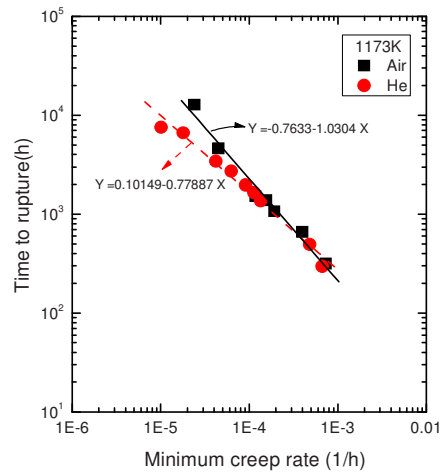


Fig. 4. Rupture time versus minimum creep rate.

3.2. Outer oxide layer thickness

Figure 5 shows the Cr-oxide layer thicknesses measured for specimens crept in the air and He environments. The increase in outer oxide layer thickness of air samples seems to show a parabolic curve. In case of the He specimens, the outer oxide layer thickness was thin at the early stage of rupture time, but the thickness was thicker than that in air from after 3,000h. The specimen ruptured after 7,500 h and reached over 20 μm thickness. This trend was similar to the previous results obtained at 1223K.

The reason for this can be explained, as follows. In air samples, the surface oxide structure was very dense, but in He samples the structure was more porous than in air samples. The dense oxide layer is formed owing to a high oxygen concentration in the atmosphere, and it provides a proper protection layer from surface oxidation during long-term creep time. Thus, as the creep rupture time increased, the outer oxide layer thickness in He environment was thicker than that in air, even in the low oxygen-containing He agent used in this study.

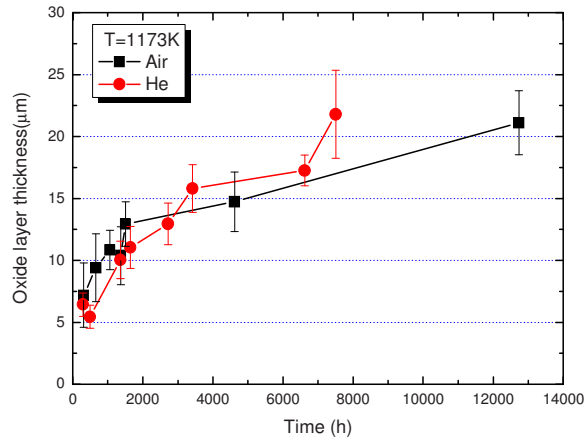


Fig. 5. Change of outer oxide layer thickness measured for the specimens crept in air and He environments.

In addition, since Alloy 617 is a chromium oxide forming alloy on the surface, a Cr_2O_3 layer was formed on the surface during creep exposure [4]. A thin internal sub layer consisting of (Cr, Al, Ti) oxide was formed just beneath the Cr_2O_3 layer. A thick carbide-depleted zone developed by a reaction of the chromia and carbide precipitates below the thin internal sub layer. Low stress specimens 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. Consequently, it is found that creep rupture time was closely related to oxide layer thickness formed during creep time.

4. Conclusions

There were no large differences in the shapes of the creep curves between air and He environments of Alloy 617. 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 air. At low applied stress levels, the rupture time of specimens crept in He was shorter than that in the air. The outer Cr-oxide layer and inwardly protruded Al-oxide layer increased with the rupture time. The thickness of the outer oxide layer in He environment slowly increased with the rupture time. The increase in the outer oxide layer thickness of air samples seems to show a parabolic curve. It is found that creep rupture time was closely related to oxide layer thickness formed during creep time.

Acknowledgements

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