Corrosion Behavior of Alloy 617 in High Temperature Gaseous Impure Helium Environment

Sujin Jung [a*], Gyeong-Geun Lee [a], Dong-Jin Kim [a]
Nuclear Materials Research Division, Korea Atomic Energy Research Institute, 989-111 Daedeok-daero, Yuseong-gu,
Daejeon, 305-353,
[*]*Corresponding author: sjjung921@kaeri.re.kr*

1. Introduction

A very high-temperature gas reactor (VHTR) is one of the next-generation nuclear reactors owing to its safety, high energy efficiency, and proliferation-resistance. The coolant of a VHTR is inert helium gas with a high thermal conductivity. The heat is transferred from the primary helium loop to the secondary helium loop through an intermediate heat exchanger (IHX). The structural material for an IHX is exposed to a high temperature of up to 950°C and gas pressure difference of up to 8 MPa. Under a VHTR environment, Alloy 617 is being considered a candidate Ni-based superalloy for the IHX of a VHTR because of it has good creep resistance, phase stability, and corrosion resistance at high temperature. Helium which inevitably includes impurities such as H_2, CH_4, CO and H_2O is used as a coolant in a VHTR. Material degradation is aggravated by oxidation, carburization, and decarburization under an impure helium environment.

In this study, high-temperature corrosion tests were carried out at 850-950°C in air and impure helium environments.

2. Experimental

The material tested was a commercial grade Alloy 617 plate from Special Metals (Huntington, West Virginia, US). The chemical composition of Alloy 617 is shown in Table 1. The plate was cut into small coupons of ~10×11×1 mm in size using a wire cutting technique. No thermal treatment was carried out before machining. The surface of the specimen was polished mechanically using 1500 SiC paper, and using ultrasonic cleanings in acetone and ethyl alcohol for removal impurities.

Table 1 Chemical compositions of Alloy 617 used in the study (wt%)

Ni	Cr	Co	Mo	C	Mn	S
53.16	22.16	11.58	9.80	0.08	0.11	0.001
Si	Cu	Al	Ti	Fe	P	B
0.06	0.08	1.12	0.35	1.49	0.08	0.002

The high-temperature corrosion tests of Alloy 617 specimens were carried out at 850,900, and 950oC in impure helium and air environment.

The impure helium composition was fixed as 200 ppm H_2, 50 ppm CO, 20 ppm CH_4, and H_2O < 2 ppm, and the flow rate of the gas was 50cm^3/min. The specimens were heated at a rate of 10°C/min, and the duration of the holding period at a test temperature was up to 250h. The air environment test was carried out in static air condition for up to 2500 h.

The weight change of the specimen was measured using a precision balance with 1×10^{-5} g accuracy. A scanning electron microscope (SEM) with Energy-dispersive X-ray spectroscopy (EDS) was used to observe the microstructures and analyze the composition of the specimens. A transmission electron microscope (TEM) analysis was performed on the JEOL JEM-2100F(HR).

3. Results and Discussion

3.1 Weight Changes

High-temperature corrosion tests were performed in air and impure helium environments, to measure the weight change. The specimen weight increased with an increase of the exposure time and temperature, and the rate of weight changes decreased with an increase of the time. The square of the weight change and time clearly shows the linear relationships, and this relationship is known as a parabolic oxidation of metals. Alloy 617 specimens showed a parabolic oxidation behavior for all temperatures and environments.

The oxidation behavior by diffusion is very sensitive to temperature, and this tendency can be expressed using the Arrhenius equation. Fig. 1 shows the relation between the inverse of temperature versus log k_p. The activation energy for oxidation was 154kJ/mol in an impure helium environment, and 261kJ/mol in an air environment.

32. Microstructure

Fig. 2 shows the cross-section of a specimen corroded in an impure helium environment. The outer oxide layer has a smooth and uniform. Below the outer oxide layer, internal oxides with dark gray intruded the matrix, and some internal oxides grew heavily along the grain

boundaries. The carbide depleted zone without grain boundary carbides was observed.

The thicknesses increased with the test time, and the increase rate of the thickness was decreased with time. The thickness change of the layers followed the parabolic rate law like a weight change result.
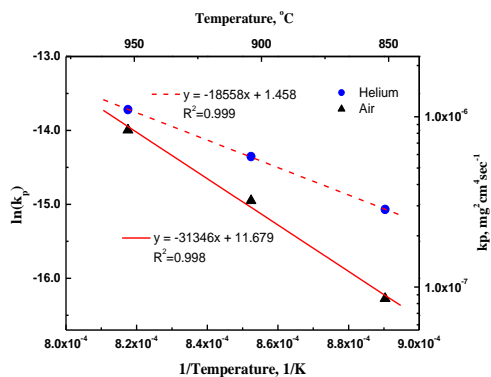

Fig. 1 Calculation of the activation energy for the oxidation of Alloy 617 in impure helium and air environment.
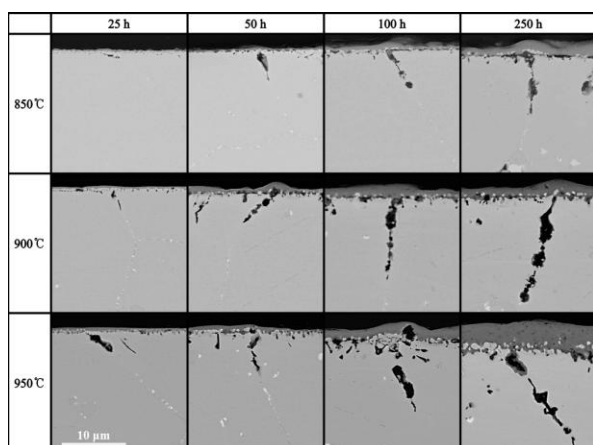

Fig. 2 BS SEM micrograph of the corroded specimens in the impure helium environment.

To identify the morphology of the surface outer oxide layer, a transmission electron microscope (TEM) analysis was performed, and the results are given in Fig. 3. The grains in the outer oxide layer for a corroded impure helium environment were small and similar in grain. On the other side, corroded specimen in an air environment showed a coarse grain.

4. Conclusions

Alloy 617 specimens showed a parabolic oxidation behavior for all temperatures and environments. The activation energy for oxidation was 154kJ/mol in a helium environment, and 261kJ/mol in an air environment. The scanning electron microscope (SEM) and energy-dispersive x-ray spectroscopy (EDS) results revealed that there were a Cr-rich surface oxide layer,

Al-rich internal oxides and depletion of grain boundary carbide after the corrosion test. The thickness and depths of the degraded layers also showed a parabolic relationship with time. A corrosion rate of 950°C in impure helium was higher than that in an air environment, caused by the difference in the outer oxide morphology.
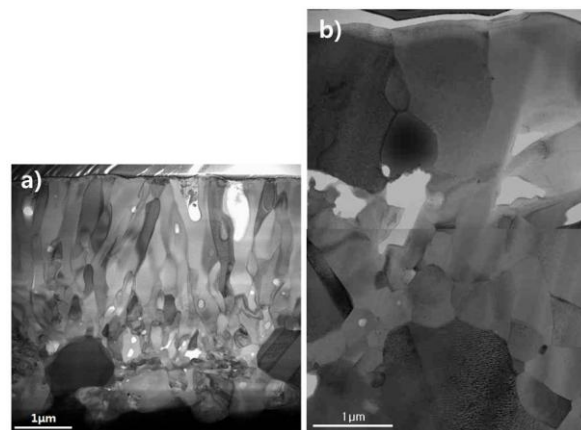

Fig. 3 TEM micrographs of the outer oxide layer of (a) the specimen corroded in impure helium environment, and (b) the specimen corroded in air environment. The test condition was at 950°C for 250 h.

REFERENCES

[1] R. Elder, R. Allen, Prog. Nucl. Energy 51, 500, 2009.
[2] T. Hirano, M. Okada, H. Araki, T. Noda, H. Yoshida, and R. Watanabe, Metall. Trans. A. 12, 451, 1981.
[3] W. Ren and R. Swimdeman, J. Pressure Vessel Technol. 131, 024002, 2009.
[4] R. H. Cook, Nucl. Technol. 66, 283. 1984.
[5] N. Birks, G. H. Meier, F. S. Pettit, Introduction to the High-Temperature Oxidation of Metals 2nd, Cambridge University Press, UK, p.49, 2006.
[6] D.-J. Kim, G.-G. Lee, S. W. Kim, and H. P. Kim, Corros. Sci. Technol. 9, 164, 2010.
[7] G.-G. Lee, S. Jung, D. Kim, W.-G. Kim, J. Y. Park, and D.-J. Kim, Kor. J. Mater. Res. 21, 596, 2011.