

A study on Corrosion Behaviors of SS 316 L in Liquid Gallium Environments

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1. Introduction

For recycling spent fuels from nuclear power plant, liquid metal fast breeder reactor (LMFBR) is one of promising candidates among Gen IV nuclear energy system. Among various liquid metals, sodium is a spotlighted coolant for the fast reactor. However, high activity of sodium with water and air is the major disadvantage that forces to search for alternatives. On the other aspects, the liquid metals including gallium generally interact with structural materials, and it may cause attack of materials in certain condition.

The purpose of this work is to examine the interaction between steels and liquid gallium to evaluate the potential application of gallium for fast reactor coolants. In fact, gallium could be a good candidate for use as a liquid metal in the field of Gen IV nuclear systems since it has low melting point (29°C), high boiling point (2204°C) and high safety against explosion. However, gallium has a high affinity for many metals and alloys, especially iron [1]. For the prevention of liquid gallium corrosion with stainless steels, an active control of oxygen partial pressure which has been extensively studied for lead-bismuth corrosion could be adopted in this gallium environment [2, 3].

2. Corrosion experiments

In this study, SS 316L was exposed to static gallium at 500 °C for 700 hr in air and vacuum conditions (5×10^{-6} torr). At each conditions, SS 316L specimens were exposed to liquid gallium for 17, 140, and 307 hrs, respectively. After each test, gallium was observed to diffuse out along the surface of specimen as shown in Fig. 1.

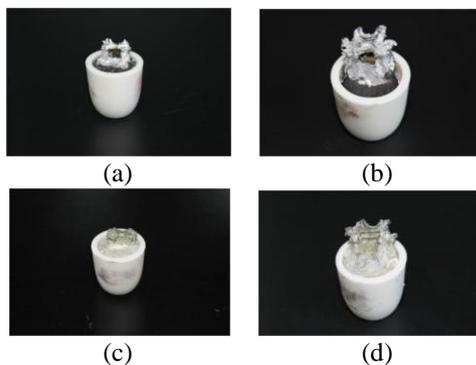


Fig. 1. Images of SS 316L specimens in alumina crucibles, immediately after the experiment. Each specimen was exposed to gallium for 140(a) and 307(b) hr in air and 140(c) and 307(d) hr in vacuum conditions.

The results have shown that this material is considerably attacked by liquid gallium at high temperature.

2.1 Results of Corrosion Tests for SS 316L

The SS 316 L specimens that were exposed to gallium showed significant corrosion at 500°C and developed a thick reaction layer. Grain boundary attack was not observed. The EPMA quantitative analysis shows that the reaction layer is composed by mainly FeGa_3 and some CrGa_4 , Ni_2Ga_3 and Ga_2O_3 shown in Fig. 2 and 3 [4, 5, 6].

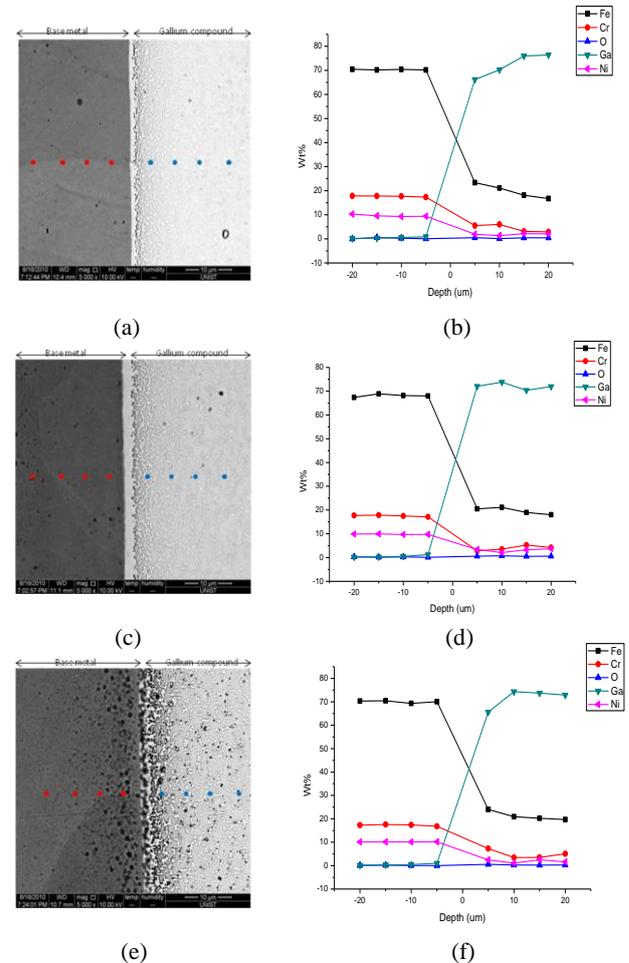


Fig. 2. SEM images of SS 316L after exposure to stagnant gallium at 500°C in air for 17(a), 140(c), and 307(e) hr, along red (steel region) and blue (gallium compound region) spots indicating analysis positions for EPMA (left) and quantitative analysis of Fe, Cr, O, Ga, and Ni obtained by EPMA (right).

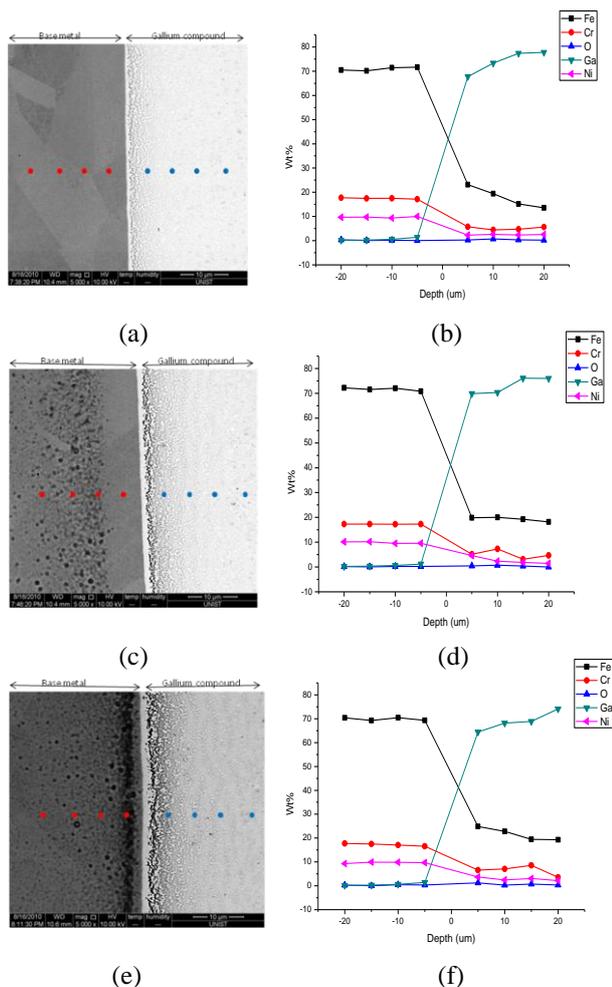


Fig. 3. SEM images and EPMA results of SS 316L after exposure to stagnant gallium at 500°C in vacuum for 17(a, b), 140(c, d), and 307(e, f) hr, respectively, where red (metal region) and blue (gallium compound region) spots in each image indicate the positions for EPMA.

From these results, it was found that the longer exposure time to gallium caused the thicker layer at the interfaces.

2.2 Active Control of Oxygen Partial Pressure

Many corrosion experiments in lead-bismuth environment were studied by using active oxygen control system [2, 3]. For the formation of chromium oxide layer on the surface of SS 316L, the value of oxygen partial pressure (p_{O_2}) in this system necessarily stays between the values of Ga_2O_3 and Cr_2O_3 indicated in Table I.

Table I: The thermodynamic conditions at 500°C

Oxides	ΔG (J/mol)	H_2/H_2O ratio	p_{O_2} (atm)
Ga_2O_3	-840,000	$1.2818 \cdot 10^5$	$1.483 \cdot 10^{-38}$
Cr_2O_3	-987,502	$2.6863 \cdot 10^8$	$3.71 \cdot 10^{-42}$

To increase corrosion resistance at high temperature, pre-oxidation methods of SS 316L at high temperature also could be one of the options. To evaluate pre-oxidation approach, corrosion experiments are now in process for pre-oxidized SS 316 L in gallium at 500°C for 700 hr in air and vacuum conditions. The steels were pre-oxidized at 500°C for 24 hrs under controlled condition ($p_{O_2}=10^{-39}$ atm) and shown in Fig. 4. As shown in Fig. 4, the pre-oxidized SS 316L in controlled condition formed Cr_2O_3 layer on its surface. Moreover, corrosion experiments under controlled condition by an active control of oxygen partial pressure in gallium environment are now in process.

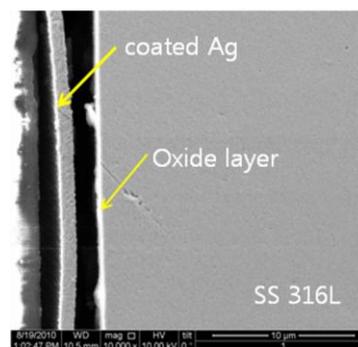


Fig. 4. SEM image of pre-oxidized SS 316L (silver coated) under controlled condition ($p_{O_2}=10^{-39}$ atm).

3. Conclusions

In this study, the compatibility of SS 316L in the liquid gallium has been investigated at 500°C. The results have shown that this material is severely attacked by the liquid metal.

For preventing liquid metal attack, a series of corrosion test of pre-oxidized samples is currently in process in high temperature gallium environment.

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