

Experimental Study on Corrosion Behaviors of SS 316L in High Temperature Liquid Metals

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1. Introduction

This study focused on liquid gallium and gallium alloys as potential coolant for the next generation nuclear reactor system. The element of gallium possesses unique properties as follows. It is very stable in air or water, having a very low melting point, and a very high boiling point. It melts at 29°C, and suitable alloying might be capable of lowering the melting point to below room temperature by alloying with Sn and Zn [1, 2]. The boiling point is as high as 2204°C. There is no issue of gallium for activity increase by irradiation in nuclear reactor environment. However, the absorption cross section of gallium is rather high, 2.2 barns per atom, which is severe handicap, but since the cross section might be reduced by proper alloying. In the viewpoint of compatibility of coolant, which is main interest of this study, gallium has a high affinity for many metals and alloys [3,4], especially steels. In this study, as-received and pre-oxidized specimens of SS316L under different conditions were tested and analyzed to understand general corrosion behaviors of structural materials in liquid gallium and gallium alloy.

2. Corrosion experiments

In this study, SS 316L was exposed to static gallium and gallium alloys at 500°C for up to 700 hrs. All specimens for corrosion test with dimensions of 30 mm in length, 10 mm in width and 3 mm in thickness were cut by high pressure water jet process to avoid thermal stress. Specimens were pre-oxidized at 500°C air for 24 and 100 hr, and at controlled O₂ for 24 hr, respectively. Each specimen was put into alumina crucible for avoiding precipitate from container. Tests were conducted at air, high vacuum (5x10⁻⁶torr), and controlled O₂ conditions.

2.1 Active Control of Oxygen Partial Pressure

Many corrosion experiments in lead-bismuth environment were studied by using active oxygen control system [5]. For the formation of chromium oxide layer on the surface of specimens, the value of oxygen partial pressure (p_{O₂}) in this system necessarily stays between the values of Ga₂O₃ and Cr₂O₃ as indicated in Table I.

Table I: The thermodynamic conditions at 500°C

Oxides	ΔG (J/mol)	H ₂ /H ₂ O ratio	p _{O₂} (atm)
Ga ₂ O ₃	-840,000	1.2818*10 ⁵	1.483*10 ⁻³⁸
Cr ₂ O ₃	-987,502	2.6863*10 ⁸	3.71*10 ⁻⁴²

2.2 Results of corrosion Tests

The SS 316L specimens that were exposed to gallium showed significant corrosion at 500°C and developed a thick reaction layer as shown in Fig. 1, and grain boundary attack was not observed. The thickness of reaction layer developed at each gaseous condition (air, vacuum and controlled O₂) is measured. In pure gallium environment, as-received specimens developed the most thick reaction layer compared to other specimens exposed to gallium alloy environments as shown in Fig. 2.

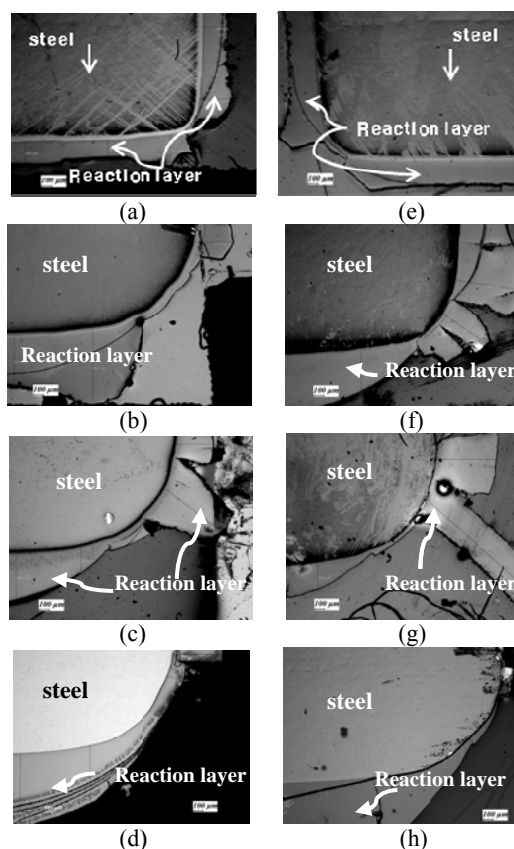
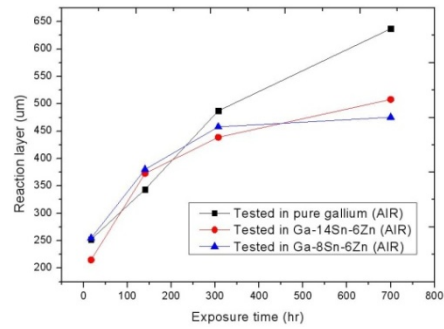
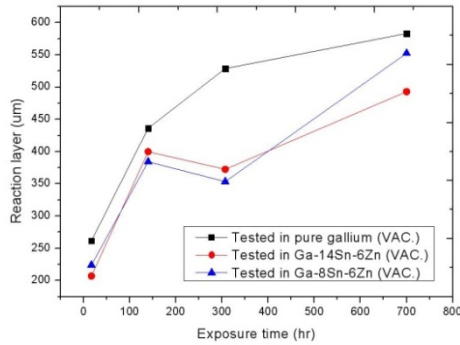


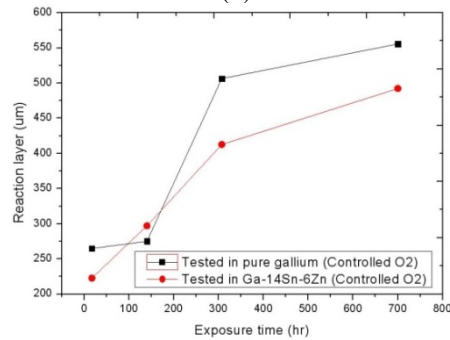
Fig. 1. Optical images of as received specimens after exposure to static gallium for 17 (a), 140 (b), 307 (c), and 700 (d) hrs in air condition and 17 (e), 140 (f), 307 (g), and 700 (h) hrs in vacuum condition, respectively.



(a)



(b)



(c)

Fig. 2. Thickness of reaction layer of as-received SS 316L exposed to pure gallium and gallium alloys (Ga-14Sn-6Zn and Ga-8Sn-6Zn) at 500°C, (a) in air condition, (b) in vacuum condition (10^{-6} torr), and (c) in controlled O_2 condition, respectively.

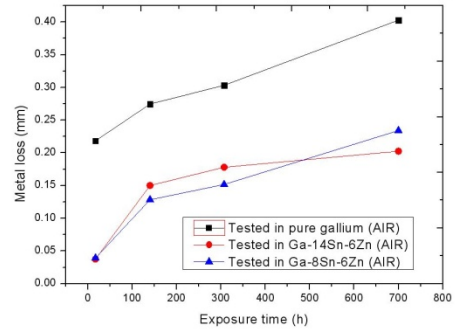
In the metal loss, as-received specimens exposed to pure gallium showed most severe corrosion as shown in Fig. 3. This is due to high dissolution rate of constituents of specimen by gallium.

3. Conclusions

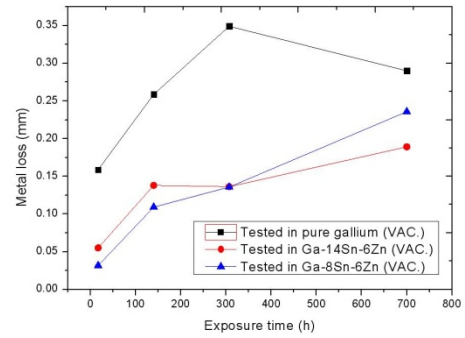
Based on the results from this study, specimens in gallium alloys showed higher corrosion resistance than in pure gallium at high temperature air condition.

However, the thickness of reaction layer formed even in gallium alloy condition is considered relatively higher than what can be generally expected from other liquid metal coolant condition including Na or Pb-Bi.

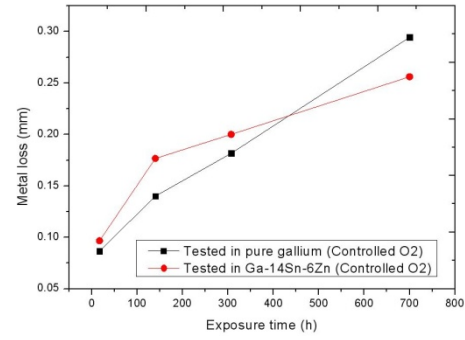
By proper alloying to produce protective layer formation need to be pursued. In this case, the gallium alloys (not pure gallium) would be better choice as liquid metal coolant materials for the candidate of next generation coolant in terms of material compatibility.



(a)



(b)



(c)

Fig. 3. Metal loss of as-received SS 316L exposed to pure gallium and gallium alloys (Ga-14Sn-6Zn) at 500°C, (a) in air condition, (b) in vacuum condition (10^{-6} torr), and (c) in controlled O_2 condition, respectively.

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