

## A Study on Corrosion Behaviors of SS 316L in Liquid Metals for Nuclear Application

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### 1. Introduction

Since liquid metals such as sodium and lead or LBE are excellent heat transfer agents, extensive researches have been performed for the use as coolants of fast breeder reactors. While sodium has been challenged by its high chemical activity with water and air, lead or LBE have known to have issues related to corrosion with structural alloys at high temperature and Po-generation in Pb-Bi cooled nuclear systems. This study suggests gallium as potential coolant for the primary or secondary circuit of advanced nuclear systems. Gallium possesses a low melting point (29°C), a high boiling point (2204°C) and no issue of chemical activity and radioactivity increase by irradiation. However, the absorption cross section of gallium is rather high, 2.2 barns per atom [1], which is a drawback, but it can be manageable to a certain degree because the cross section could be reduced by proper alloying with elements with lower absorption cross section.

Meanwhile, stainless steels have been used for structural materials in various industries including nuclear energy system because of its favorable mechanical and material properties. If there is no corrosion problem with liquid gallium, stainless steels can be good structural materials for the application. For the prevention of liquid gallium corrosion, an active control of oxygen partial pressure which has been extensively studied [2, 3] for preventing Pb or LBE corrosion with structural materials can be adopted.

### 2. Corrosion experiments

In this study, all specimens for corrosion test with dimensions of 30 mm in length, 10 mm in width and 3 mm in thickness were cut by water-jet to avoid thermal stress. Prior to exposure to gallium, each specimen was mechanically polished by SiC papers, diamond suspension (6µm, 3µm, and 1µm), and finally alumina paste down to 0.04µm, then ultrasonically cleaned with deionized water for 30 min.

In order to reduce neutron absorption cross-section of pure gallium liquid metal, zinc and tin that have lower absorption cross-sections were chosen for the use of ternary alloy system. At the compositions of Ga-14Sn-6Zn, eutectic alloys are built up with lower melting point (21°C) [4].

The types of test specimen in this study were as follows. As-received specimens (SS 316L), pre-oxidized (at 500°C air for 24 and 100 hrs, mainly iron

oxide) specimens and pre-oxidized (at 500°C controlled O<sub>2</sub> for 24 hrs, only for the formation of chromium oxide) specimens (as shown in Fig. 1) were exposed to liquid gallium and gallium alloys (both Ga-14Sn-6Zn and Ga-8Sn-6Zn) at 500°C for up to 700 hrs. The cover gas conditions in test system were also varied as air, high-vacuum and controlled O<sub>2</sub> conditions.

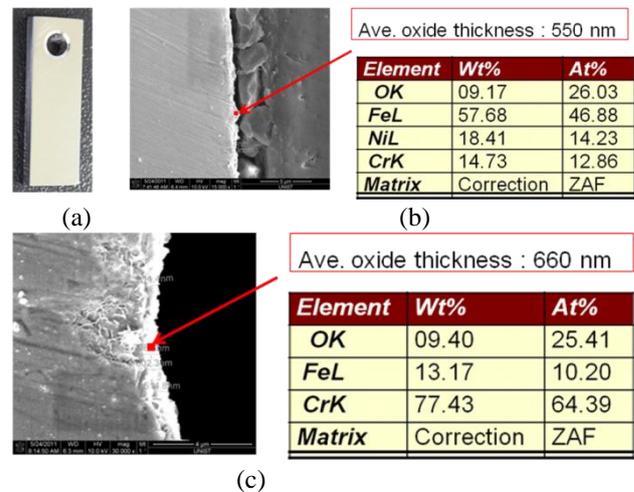


Fig. 1 The image of as-received specimen (30x10x3 mm) (a), the cross section image of pre-oxidized (at 500°C air for 24 hrs) specimens (b) and the cross section image of pre-oxidized (at 500°C controlled O<sub>2</sub> for 24 hrs) specimens (c)

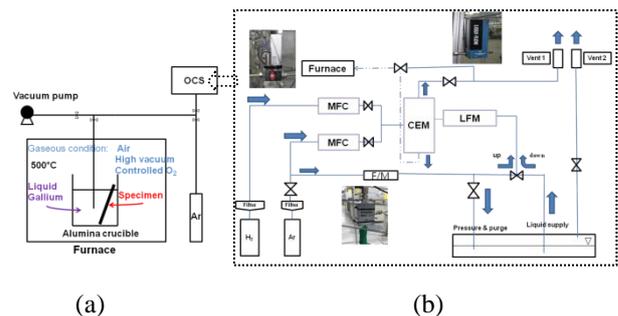


Fig. 2 The total experimental system to change gaseous conditions (a) and the schematic diagram of oxygen control system (b)

To actively control the oxygen partial pressure in liquid gallium environment at high temperature, experimental system which is similar to ones used previous studies [2,3] was designed and assembled in this study as shown in Fig. 2.

Table I. Physical properties of alloying elements

Element	Symbol	Atomic no.	Nominal density (g/cm <sup>3</sup> )	$\Sigma_a$ (cm <sup>-1</sup> )
Gallium	Ga	31	5.91	0.1480
Zinc	Zn	30	7.133	0.02333
Tin	Sn	50	7.298	0.07230

### 3. Results

After exposure of specimens to liquid gallium at 500°C for up to 700 hrs, metal loss, weight change and thickness of reaction layer were measured. Also, with the increase of the exposure time, the volume and the weight of specimens decrease, but thickness of reaction layer increased in general. There is no clear evidence for preferential attack along grain boundary which is commonly observed in some liquid metal environment at high temperature.

The volume of the specimens was significantly reduced due to dissolution of main constituents and reaction layer was formed on the surface of the specimens. The reaction layer was analyzed with EDS and shown in Fig. 3.

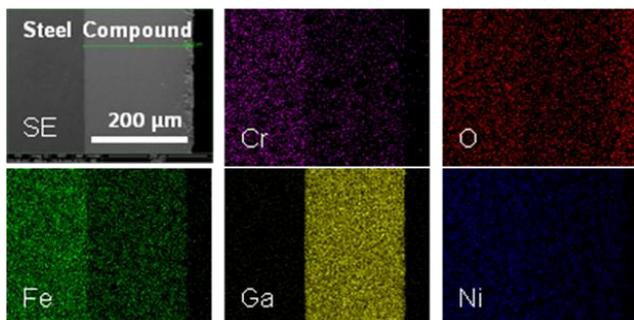


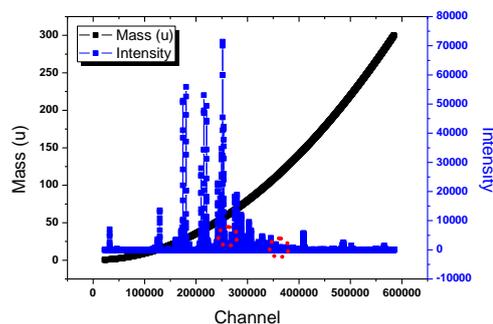
Fig. 3 SEM x-ray mapping images (x600) of pre-oxidized (at 500°C air for 24 hrs) specimens exposed to pure gallium at 500°C air for 17 hrs

The major difference of specimens tested in gallium alloys is that a small amount of Zn was detected in reaction layer. In contrast, Sn was not observed in the reaction layer based on TOF-SIMS (Time of Flight Secondary Ion Mass Spectrometry) analysis as shown in Fig. 4.

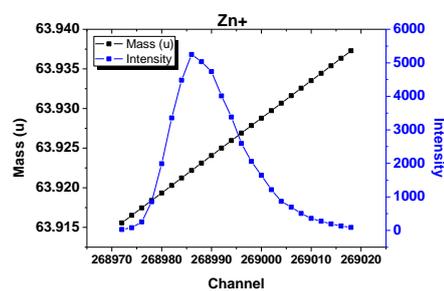
### 4. Conclusion

All specimens exposed to gallium alloys (Ga-14Sn-6Zn and Ga-8Sn-6Zn) showed lower corrosion rates than that exposed to pure gallium. Based on the results from this study, it is concluded that AISI 316L exhibited higher compatibility in gallium alloys environment than in pure gallium at high temperature. Authors would suggest that a detail study to improve the compatibility of structural materials by proper

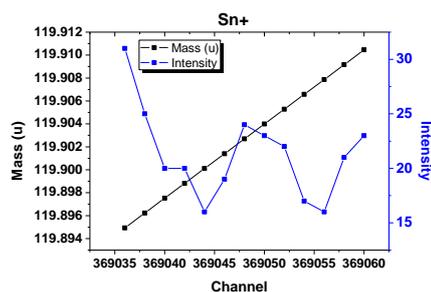
alloying of structural alloys to form protective layers including Al<sub>2</sub>O<sub>3</sub> and SiO<sub>2</sub> need to be pursued.



(a)



(b)



(c)

Fig. 4 TOF-SIMS analysis on the surface where the reaction layer of as-received specimen exposed to Ga-8Sn-6Zn alloys (a) total ion distribution (b) Zn+ and (c) Sn+

### REFERENCES

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