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Corrosion Behavior of 316 Stainless Steel in Lead-Bismuth Eutectic (LBE)

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1. Introduction

As a part of the development of a high temperature irradiation device for irradiation tests of SFR fuels and materials at the HANARO reactor [1], the Pb-Bi eutectic (LBE) alloy as a candidate thermal media of a capsule was chosen due to its high boiling temperature and no reactivity hazard [2]. However, the corrosion problem for steels becomes a critical barrier for the high temperature and longtime application. The stainless steels corrosion resistance is well known to be highly depend on the oxygen concentration of LBE. For oxygen concentrations lower than 5×10^{-8} w/o austenitic steels in LBE, at 550 ºC, undergo a dissolution process, whereas for higher concentration an oxidation process occurs preventing the material dissolution [3].

Many researchers have shown that these problems will be solved near future with the introduction of advanced technologies. At present, LBE is expected to perform reliably well at relatively high temperature.

The expected problems for the technological application of the LBE are investigated through a series of corrosion tests. This test could provide a reasonable demonstration and guidance on the limitations or applications of the candidate structural materials in a molten LBE.

2. Experimental

The material of the corrosion specimens is the austenitic stainless steel 316 of 150mm long and 12 mm in diameter, the composition of which is listed in table 1. A block type of LBE ingot (5x15x5cm) is placed in the melting device inside of glove box. After melting of the ingot a small rod type LBE of around 25g are made to be placed in each tube specimens, which make it easy to contact with molten LBE. The immersion time is 1500 hrs, which is equivalent to 2.3 cycles in HANARO. The LBE materials with different oxygen contents were used for the test; one from as-received (30 ppm) and another from oxygen-controlled (10 ppm). He gas with 5% hydrogen was used to get low oxygen content in the LBE. Chemical and physical analyses were carried out by using ICP-AES/MS and thermo-gravimetry. In addition, a phase analysis by XRD and a measurement of the oxygen content by an inert gas fusion IR detection were carried out before filling a LBE sample into the SS316 tube specimens. The results of the analyses of a LBE samples are listed in the table 2. After inserting a rod type of LBE into the specimens, the end plugs of the tube specimens were sealed by TIG welding. The corrosion test was performed in the stagnant liquid metal at constant temperatures of 470 and 700 ºC. After corrosion tests, metallographic examinations of all the tested samples were accomplished by an optical microscopy, a scanning electron microscopy (SEM)–energy dispersive X-ray microanalysis (EDX).

Table 1. Chemical composition (w/o) of 316 stainless steel

Cr	Ni	Mo	Mn	P	S	Si	C
17.0	10	2.5	2.0	0.045	0.03	1.00	0.03

Table 2. Chemical composition (w/o) of LBE

Pb	Bi	Ag	Cd	Cr	Cu	Fe	Ni	Sn	Sb
44.2	55.7	13.2	10.4	<12	<10	5.5	<10	929	9.2

3. Results and Discussion

The samples tested at 400 ºC, as expected, show an almost intact oxide layer after 1500 h as shown in Fig 1. The EDX analysis indicates that the steel composition is not changed in the vicinity of the surface. This points out that no LBE penetration into base metal occurs at the surface of the base metal. This observation is in agreement with the results reported by Glasbrenner [4]. However, at 700 ºC, the sample tested in LBE show a material dissolution on most of the oxide layer as shown in Fig.2. Depth attacks were observed in the metallographic sections of the samples. From the metallographic observation, the depth of the LBE penetration in the samples after 1500 h of an exposure ranged from 110μm to around 30 μm. The attacks tend to follow the grain boundaries, as can be seen in Fig 3. The figure showed that the oxide layer is mainly composed of iron, chromium, nickel, and oxygen. The observed corrosion mechanism seems to be the dissolution of the steel elements in the liquid metal. A similar mechanism has been reported by Gorynin [3] and Muller [5].

As the test temperature increase from 400 to 700 ºC the liquid metal penetration attack through the oxide layer may become much more active and more severe near the surface of the base metal. The effects of oxygen contents of the LBE seem to be almost negligible under the test conditions. This means that as the oxygen contents of the LBE are not so much different, any differences are not observed.

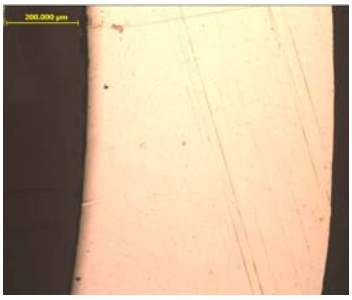

Fig. 1. SEM of cross-sections after 1500h at 470 ºC.

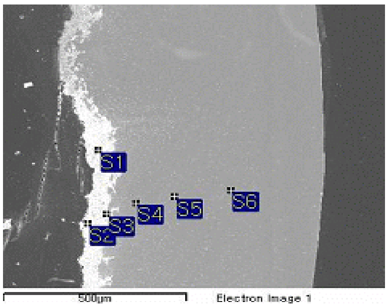

Fig. 2. SEM of cross-sections after 1500h at 700 ºC.

The concentration profiles shown in Fig.3 indicate that regardless of the oxygen contents of LBE chosen for the tests, the alloying elements such as Fe, Cr, and Ni were present in the oxide layer.

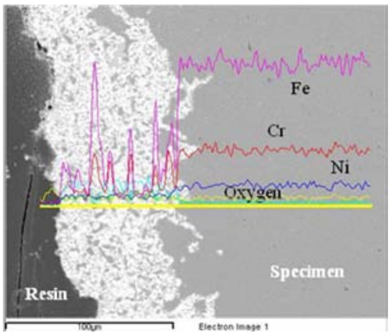

Fig. 3. SEM of cross-sections and EDX concentration profiles of 316 stainless steel specimen exposed to the molten LBE at 700 ºC for 1500h.

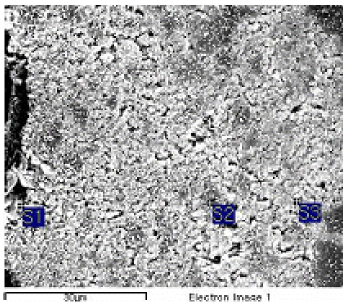

Fig. 4. SEM micrograph of the oxide layer of the 316 stainless steel specimen (White: oxygen rich, Black: Base metal)

Fig 4 shows the morphology of the oxide areas which shows non-uniform structure. This figure shows that selective penetration of LBE due to different oxygen activity of base metal may cause them to have non-uniform structure over the substrate surface. This feature is similar to that described in [6].

4. Conclusions

The corrosion behavior of the chosen stainless steel materials was investigated to examine their suitability as a container material in stagnant LBE at a constant temperature of 470 and 700 ℃ for 1500 hours. The test results showed that at a relatively low temperature of 400 ℃, no LBE penetration into base metal occurs at the surface of the base metal while at a high temperature of 700℃, the austenitic steels exhibited a wide range of attacks up to 110 μm and the dissolution of steel elements occurred. This was confirmed by a SEM-EDAX analysis. The content of oxygen chosen for the tests could not provide an effective way of protecting steel against corrosion. Thus, it can be concluded that a LBE container is expected to maintain its structural integrity to perform a relatively high temperature test of HANARO for 2.3 cycles.

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