Corrosion Behavior of Steels and Oxygen Diffusion in Heavy Liquid Metal

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1. Introduction

HYPER(Hybrid Power Extraction Reactor) is the accelerator driven transmutation system developed by KAERI(Korea Atomic Energy Research Institute). HYPER is designed to transmute long-lived transuranic actinides and fission products such as Tc-99 and I-129. Lead-Bismuth eutectic(LBE) alloy was determined as a spallation target and coolant material of HYPER due to its high production rate of neutrons and its effective heat removal. However, LBE has a great corrosion problem at high temperature[1,2].

In this study, we performed static corrosion tests of steels such as 316LN and HT-9 with three different oxygen contents at 650℃. And, oxygen diffusion behaviors in the liquid metal were also investigated.

2. Material and Methods

Fig.1 shows the layout of static corrosion test facility. Al_2O_3 crucible pot are filled with Pb-Bi and heated to a certain temperature. Each crucible contains 32g of Pb-Bi.

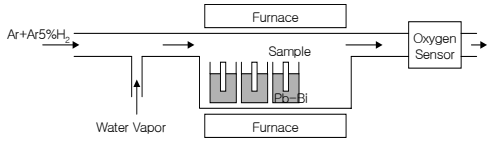

Fig.1. Schematic layout of static corrosion test facility

The static corrosion experiments were performed with three different oxygen contents, which are $<10^{-8}$ wt%(reduced),10^{-6}wt% and 10^{-5}wt%. The exposure time for corrosion test was up to 1500 hours.

The oxygen concentration in corrosion test was controlled by adjusting the H_2 and H_2O vapor ratio. Eq (1) is used to calculate the corresponding oxygen partial pressure. Then, Eq (2) is used to determine the pressure ratio of H_2 and H_2O[3]. The H_2O pressure is set to be 15.94 bar.

$$a_0 = \frac{C_0}{C_0^*} = \left(\frac{P_{O_2}}{P_{O_2}^*}\right)^{1/2} \quad (1)$$

$$P_{O_2} = \frac{P_{H_2O}^2}{P_{H_2}^2} \exp\left(\frac{2\Delta G_{H_2O}}{RT}\right) \quad (2)$$

,where Co is oxygen concentration(wt%), Co^* is the solubility of oxygen in Pb-Bi.

When a reduced atmosphere($<10^{-8}$wt%) is needed, Ar5%H2 gas is forced to flow with the rate of 35cm^3/sec for 3 days.

Oxygen diffusion behavior in liquid metal can be modeled with solutions of the diffusion equations, Fick' laws [4]. The diffusion coefficient of oxygen in liquid metal is estimated by the equation investigated by Wilke-Change[5].

3. Results and Discussion

Stagnant corrosion experiments were performed to investigate the degree of corrosion damage for HYPER materials due to the dissolution by stagnant Pb-Bi. Fig. 2 shows SEM and EDX results of 316LN with reduced oxygen for 500hr.

As shown in Fig. 2, dissolution attack is clear for the 316LN sample and the corrosion pattern is homogeneous through the sample surface. The maximum depth of dissolution is about 40um. Based on the EDX analysis results,Ni has a higher tendency to be dissolved than Cr, and Bi has a higher tendency of penetration than Pb.

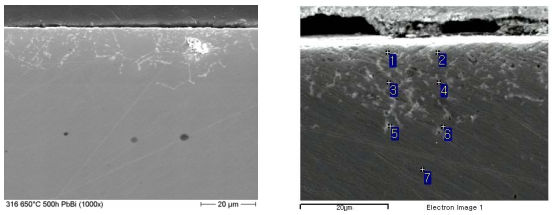

Fig.2. SEM and EDX results of 316LN at 650 ℃.

Fig. 3 shows EDX result of HT-9 exposed to Pb-Bi with reduced oxygen content($<10^{-8}$ wt%) at 650 ℃ for 500hr. Based on the results, dissolution attack was not appeared and the oxygen layer was not detected. If corrosion test is undertaken for more than 1000hr~2000hr, the corrosion of steels may be severe due to the exposure of the LBE.

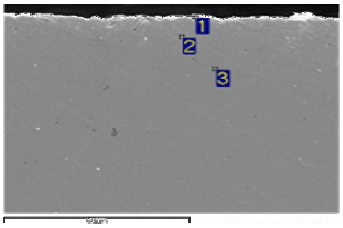

Fig. 3. EDX result of HT-9 with reduced oxygen.

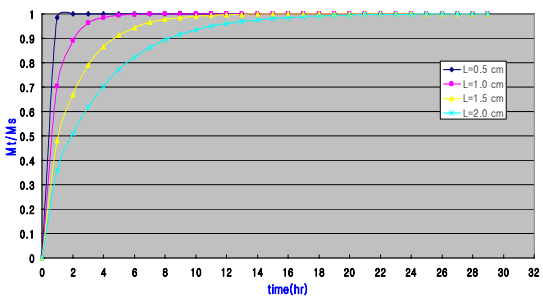

Fig. 4. Oxygen diffusion rate in Pb-Bi at 600°C.

Oxygen diffusion rate in stagnant liquid metal was estimated by oxygen diffusion model. A rigid plane of stagnant liquid metal(height:ℓ) is assumed, with a given oxygen concentration on the surface due to a set H_2/H_2O ratio in the gas phase. Fig. 4 shows oxygen diffusion rate in Pb-Bi at 600℃. From the results, the required time for oxygen diffusion from liquid metal surface to 2cm depth was 29 hr for Pb-Bi.

4. Conclusions

From the results of static corrosion tests of 316LN with reduced oxygen for 500hr, dissolution attack is clear, the maximum depth of dissolution is about 40um. The solubility of Nickel is greater than that of Iron and Chromium in LBE. 316LN austenitic steel has more Nickel than HT-9 martensitic steel. Therefore the corrosion of 316LN is severe under the reduced atmosphere due to the solubility of the Nickel. Based on the results of oxygen diffusion model in the liquid metal, the required time for oxygen diffusion from metal surface to 2cm depth was 29 hr for Pb-Bi and 31hr for Pb, respectively.

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