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Corrosion test of the ferritic-martensitic steel (Gr. 91) in molten Pb–Li

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1. Introduction

Design concepts for tritium breeding blankets for DEMO and/or fusion power plants are going to be tested by using various types of TBMs (test blanket modules) in ITER. Two TBM systems are proposed by Korea, i.e. a helium-cooled solid breeder (HCSB) blanket and a helium-cooled molten lithium (HCML) blanket, among several candidates [1,2]. Both the TBMs consist of a ferritic-martensitic steel (FMS) as a structural material. In particular, FMS contacts with flowing molten metals (Pb–Li or Li) during the operation in the case of HCML blanket. Since FMS is corrosive in a Pb–Li solution, the compatibility of structural materials with breeder materials should be investigated.

The compatibility of EUROFER with Pb–Li was tested at temperatures up to 550°C with PbLi flowing at up to 0.22 m/s for 5000 h in Europe [3]. China performed corrosion tests of CLAM in experimental loops, such as the thermal convection Pb–Li loop (DRAGON I) at 450–500°C, the high-temperature thermal convection Pb–Li loop (DRAGON II) with up to 700°C [3,4]. Japan also tested JLF alloys in the Li loop operated at up to 700°C [5]. However, Korea does not have any developed FMS nor an experience of the corrosion test of FMS in a Pb–Li loop. The current study may be a first step to the compatibility test of TBM, although the test includes only a static Pb–Li melt.

2. Methods and Results

For the corrosion test, a commercial FMS with grade 91 was used. The chemical compositions (wt.%) of the used steel were 8.29Cr, 0.50Mn, 0.89Mo, 0.08Ni, 0.08Cu, 0.25Si, 0.21V, 0.11C, 0.0393N, and Fe as balance. The FMS was previously normalized at 1900°F for 49 mins, and then tempered at 1450°F for 91 mins. Test samples with the dimension of 5 x 10 x 3 mm were cut, and selectively coated with alumina for a corrosion barrier. Alumina with the thickness of 1 μm was coated by using physical vapor deposition method. Pb–Li ingots with the chemical composition of 0.67 wt% Li (15.7 at% Li) with impurities of Ag, Bi, Cu, Fe, Si, Zn lower than 0.005 wt.% were melted in stainless steel container (316L) as shown in Fig. 1. Pb–15.7Li is known as the real eutectic alloy [6]. The Pb–Li melt was maintained at 450°C during the corrosion test. Test samples were put in the melt and corroded for 3000 h. After the corrosion test, the samples were taken out, and rinsed with C_2H_5OH + CH_3COOH + H_2O_2 solution to remove adhered Pb–Li debris on FMS surface. The microstructural observation on the FMS surface and elemental analysis was done.

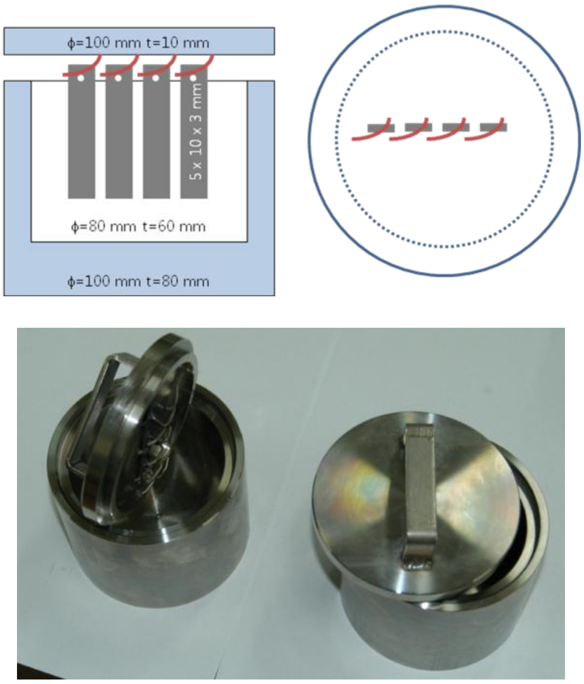

Fig. 1. Test apparatus for the corrosion test of FMS in a Pb-Li melt.

2.1 Microstructures of FMS Surface

Fig. 2 shows the microstructure of FMS corrosion tested for 3000 h. The grain boundaries are definite and grain interiors are also corroded. The corroded surface resembles the martensite laths which are original microstructure of FMS. The chemical composition was not changed after the corrosion. The corrosion behaviors are different depending on the types of FMS and test conditions. Pb–Li is known to form porous superficial layer with nickel and chromium deficient in the 316L steel [7,8]. On the other hand, homogeneous dissolution was observed in the case of martensitic steel with 9–12% chromium content [8]. In CLAM steel, chromium and iron deficient layer (a few μm thickness) was observed after 2500 h exposure in Pb–Li [4]. The preferred dissolution along martensitic lath boundaries were also observed in MANET, Optiler IVa, and F82H-mod [9].

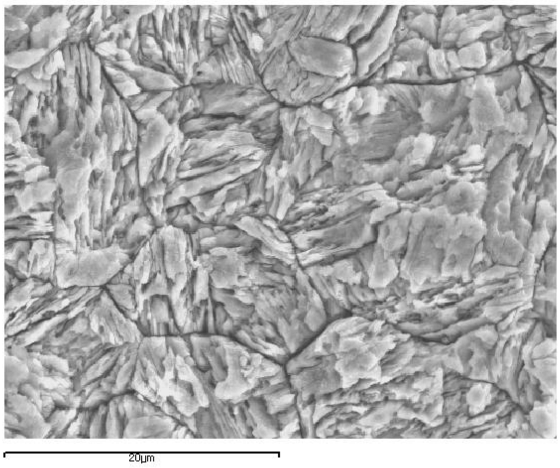

Fig. 2. Microstructures of the FMS surface which was corrosion tested in a Pb-Li melt at 450°C for 3000 h.

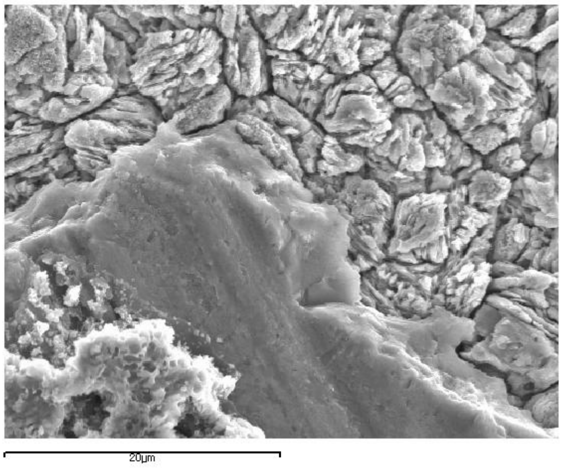

Fig. 3. Microstructures of the corroded FMS surface which was previously alumina coated.

2.2 Effect of Corrosion Barrier

Oxides such as alumina, erbia, yittria are considered as main surface coating materials because this coating can act as a magnetic insulating barrier for reducing the resistance of magnetohydrodynamic (MHD) flow. In addition, the MHD coating can also prevent the corrosion of FMS by forming a corrosion-resistant layer on FMS. In this study, alumina was coated on FMS in order to prevent the corrosion. Fig. 3 shows the microstructure of alumina coated FMS after the corrosion test. The middle of the image indicates the alumina coating layer. Alumina was broken at the upper region, and the FMS was exposed to a Pb–Li melt. The microstructure of the matrix is similar to bare FMS as shown in Fig. 2. However, a part of alumina protected the FMS from corrosion, although alumina layer was not survived successfully for 3000 h. Alumina is unstable than the lithium oxide thermodynamically [10], therefore, other oxide materials should be considered in the aspect of a long life-time.

3. Conclusions

Corrosion of FMS (grade 91) in a Pb–15.7Li melt was investigated. Grain boundaries as well as martensitic lath boundaries were preferentially corroded. In addition, alumina coating layer prevented the corrosion. The corrosion barrier, however, need to be improved or changed to other materials.

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