Corrosion test in the Experimental loop for an ITER TBM liquid breeder

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1. Introduction

An Experimental Loop for Liquid breeder (ELLI) was constructed for the purpose of validating the electromagnetic (EM) pump design, which designed and fabricated by ourselves; testing the effects of magneto-hydro-dynamics (MHD); and investigating the compatibility of PbLi using structural materials such as ferritic martensitic steel. In the ELLI, Pb-15.7Li, where Li is 15.7 at % (called PbLi hereafter), is used as the breeding material and an EM pump circulates it in the loop with the maximum flow rate of 60 lpm. The operating pressure and temperature in the loop are 0.4 MPa and 300 °C, respectively and the maximum operating pressure and temperature are 0.5 MPa and 550 °C, respectively. After the performance test on each component such as heaters, the control systems for heating the loop and the characteristic tests with a magnet and the EM pump, long-term operational tests of the EM pump were performed during three different corrosion tests [1,2].

The corrosion tests were performed in the ELLI loop by forced convection circulation using an EM pump to investigate the corrosion behavior of FMS in flowing PbLi. For the corrosion specimens, two samples were fabricated using Grade 91 FMS: tubular-type and cylindrical-type specimens. The specimens were exposed to the flowing PbLi with a speed of 0.16 m/s at 340 °C for the three different experiments. The corrosion tests by forced convection using an EM pump can conveniently vary the speed of a liquid breeder by changing the currents of the EM pump than that of using a thermal convection. [3,4].

2. Corrosion Test in the ELLI

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 pre-normalized at 1038 °C for 49 min, and then tempered at 788 °C for 91 min. The corrosion test for the FMS was performed to investigate the corrosion behavior of FMS in flowing PbLi. A 15mm length tubular-type, with a 10 mm diameter and 1 mm thickness, and a 15mm length cylindrical-type, with a 10 mm diameter, samples were fabricated using the FMS for corrosion specimens. The fabricated tubular-type and cylindrical-type specimen were fixed at a post using wires and bolted down as shown in Fig. 1. Three sets of the corrosion specimens were installed to three test pots as shown in Fig. 2. A series corrosion tests were carried out during three separate experiments. The experiments were performed at 75 h, 75 h, and 100 h for each test, respectively. After two corrosion test experiments with a duration of 150 h, some of specimens were replaced to compare the corrosion status for exposed times of the specimens. The replaced specimens were test-pot 1(#1, #2) with same material and test-pot 3(#6) with different type FMS. After installing the specimens into the loop, a corrosion test was performed while the EM pump was operating with a 0.16 m/s flow rate at 340 °C for 250 h for all three experiments. Fig. 3 shows the flow rate of the liquid breeder measured in the loop during each experiment with heat-up and shut down. After the corrosion test, the specimens were taken out from the loop, and then rinsed with C_2H_5OH + CH_3COOH + H_2O_2 solution in a ratio of 1:1:1 to remove adhered PbLi debris on FMS surface. Finally, the microstructural observation on the FMS surface and elemental analysis was done using a scanning electron microscope (SEM) equipped with an energy dispersive spectrometer (EDS) system.

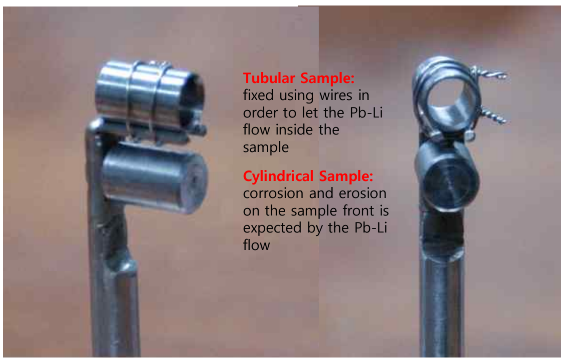


Fig. 1. Photograph of the fabricated specimens for corrosion test.

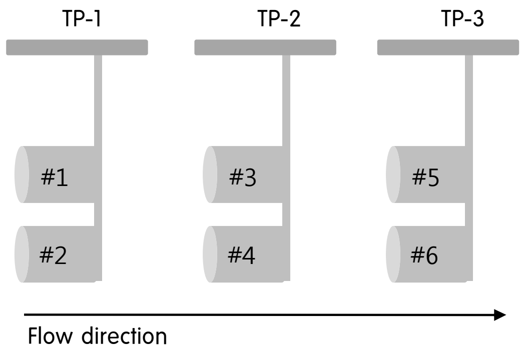


Fig. 2. Schematic diagram of specimens of the test pots.

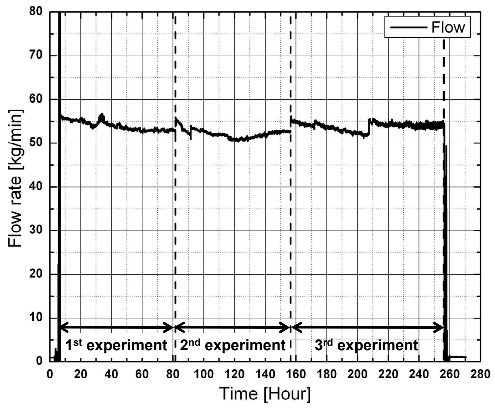
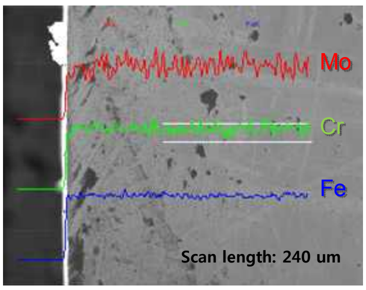


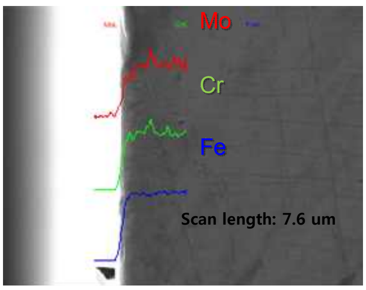
Fig. 3. Measured flow rate during three times experiments.

3. Results of the Corrosion Test

The corroded specimens were analyzed by measuring weight change, observation of corroded surfaces, respectively. A metallographic analysis was carried out by scanning electron microscope (SEM) for the two kinds of specimens. Fig. 4 demonstrates the elemental distribution at the corroded surface. EDS line-scan analyses on cross sections were performed at two ranges: up to 240 μm (Fig. 4(a)) and up to 7.6 μm (Fig. 4(b)) from the surface. The concentration profile of Fe, Cr, and Mo at the surface had not changed within the resolution limit in 150 h of exposure. Homogeneous dissolution was also observed in the case of ferritic-martensitic steel with 9–12 % chromium content in the previous investigations [5-8]. However, a depletion of Cr, Mo, W and V in the vicinity of the martensite lath boundaries was detected for the enlarged exposure in PbLi [8,9]. A slight depletion of Mo at the surface region of 1–2 μm in depth presented in Fig. 4(b) is consistent with the previous result on MANET I alloy [9].



(a)



(b)

Fig. 8. Elemental distribution at the corroded surface.

4. Conclusions

Long term operation tests with the EM pump were carried out. During the three separate experiments, an EM pump was operated for 250 h with a speed of 0.16 m/s for corrosion tests. The corrosion test for the FMS was performed to investigate the corrosion behavior of FMS in flowing PbLi. After the corrosion test, micro structural observation on the FMS surface and elemental analysis were done using a scanning electron microscope (SEM) equipped with energy dispersive spectrometer (EDS) system. Mass of samples was decreased about 0.02 % in average, which corresponded to 0.74 g/m^2 or 0.094 μm of a corrosion attack. Comparing the two ends of a tubular-type specimen, the corrosion was slightly higher at the front end than at the back end.

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