

Effect of Magnetic Field on High-Temperature and High-Pressure Water Corrosion Property of F82H

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The water-cooled ceramic breeder system is the leading choice for research and development in Japan's ITER and DEMO blankets. This type of blanket uses reduced activation ferritic/martensitic (RAFM) steel as structural material in the flow of the high-temperature and high-pressure water as coolant. There is however insufficient information regarding corrosion under fusion reactor operating conditions despite previous water chemistry and environmental strength evaluations. In particular, there are no specific studies of the effects of strong magnetic fields on corrosion behavior. Therefore, it is of great engineering importance to clarify the influence of magnetic fields on the corrosion of RAFM since the RAFM itself shows inherent ferromagnetic characteristics. In this study, we investigated whether a magnetic field affects the corrosion of Japanese RAFM steel, i.e., F82H, in high-temperature and high-pressure water. The results showed that 1.3 T of the magnetic field made no difference in the thickness of the inner oxide, but a difference in the size of the oxide particles on the surface.

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The water-cooled ceramic breeder blanket system is the primary candidate for the Japanese ITER and DEMO blanket [1]. This type of blanket uses reduced activation ferritic/martensitic (RAFM) steel as structural material and the material is subject to high-temperature and high-pressure water (HTHPW) as coolant. Studies on the compatibility of structural materials with HTHPW were found in Refs. [2–5]. For example, the effect of water chemistry on the corrosion properties of Japanese RAFM, i.e., F82H, in HTHPW was evaluated in environments with different dissolved oxygen (DO) concentrations, and it was found that the corrosion rate was reduced in environments with higher DO concentrations [2]. The effect of dissolved hydrogen (DH) was also evaluated, and it was confirmed that there was no significant difference in the amount of corrosion between the hydrogenated condition and a DO concentration of 20 ppb or less [3]. As described above, many efforts on corrosion studies regarding the effects of water chemistry and environmental strength [3–5] are continued. However, there is still a lack of corrosion characterization under the operating blanket conditions.

In particular, the fusion DEMO reactor is expected to be subjected to a high magnetic field environment of about 10 Tesla on the inboard side caused by the superconducting coils [6]. There are some reports on the relationship between magnetic fields and corrosion properties of steel materials, although the conditions were limited [7–9]. The following two effects on corrosion under the magnetic field have been evaluated. The first is that, in an environment

containing DO, the oxygen supply increases at the location of the magnetic field gradient, resulting in increased corrosion [7]. The other is that the corrosion properties are altered by inhibiting or promoting the movement of metal ion species in the liquid [8,9]. However, all of these reports were on water near room temperature, and there are no reports on RAFM in HTHPW. Therefore, it is of excellent engineering importance to clarify the effect of the magnetic field on the corrosion behavior of RAFM in HTHPW. In this study, with the establishment of a test system to conduct corrosion tests in HTHPW while applying a magnetic field, we investigated the influence of the magnetic field on the corrosion of F82H in HTHPW.

The material used in this study was F82H-BA12 [10], one of the variants of F82H. Corrosion tests were conducted using a circular tubular specimen with a test section of 50 mm in length and 1.3 mm in inner diameter under the magnetic field in HTHPW at a temperature of 300°C and a pressure of 15 MPa. Note that a flowing rate was 1 m/s inside the test section. The DO and DH concentrations were <20 ppb and 2 ppm, respectively. The magnetic flux densities applied to the inside of the test specimen were 0 T and 1.3 T. The test durations were 150 and 250 hours. After the test, a 5 mm wide specimen was cut from the center of the specimen so that the direction of the magnetic flux was toward the wetted surface of the specimen, the oxide particle size was measured by SEM, and the inner oxide film thickness was evaluated by TEM on the inner surface.

Figure 1 shows the typical specimen surface and cross-section after the test of 250 hours with and with-

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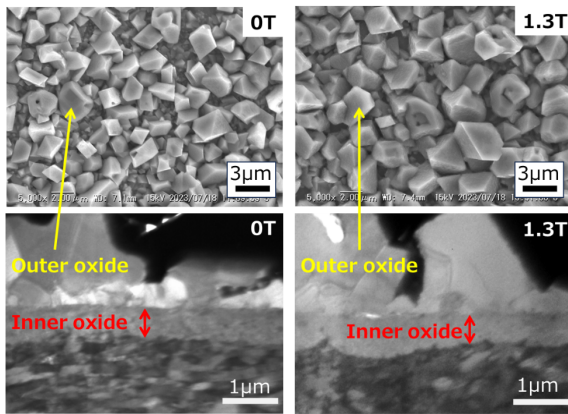


Fig. 1 Typical surface and cross-sectional images after corrosion tests at 250 h under 0 T and 1.3 T.

out a magnetic field. The oxide has a two-layer structure under both conditions, similar to the hydrostatic corrosion test results reported in previous papers [2]. That is, oxide particles were formed on the surface, and an inner oxide due primarily to oxidation of the metal matrix was formed beneath the oxide particles. It is assumed that the results were similar to those of static water because the flow velocity was low under the conditions of this test. For cross-sectional TEM observation, the thickness of the inner oxide was measured at 40 locations per condition, and the average value was calculated. By contrast, the surface oxide particle size was measured at 120 locations per condition from the SEM images of the surface, and the average value was calculated. The inner oxide thickness was $0.62 \mu\text{m}$ under the 0 T condition and $0.60 \mu\text{m}$ under the 1.3 T condition, suggesting no significant impact on the inner oxide formation. On the other hand, the surface oxide particle size was $2.35 \mu\text{m}$ under the 0 T condition. In comparison, it was $2.98 \mu\text{m}$ under the 1.3 T condition, indicating a 20% larger growth under the 1.3 T magnetic field environment.

The same analysis was performed on the 150-hour tested specimens, resulting in the plots of the average inner oxide thickness and average oxide particle size against the square root of time (Fig. 2). The time dependence of the results can be shown as a straight line passing through the origin in both cases. While the magnetic field had no significant effect on the inner oxide thickness, the oxide particle size was larger at 1.3 T. The growth rate of oxide particles was then calculated from the slope of the oxide particle size line, providing $0.193 \mu\text{m}/\text{h}^{0.5}$ at 0 T and $0.251 \mu\text{m}/\text{h}^{0.5}$ at 1.3 T.

Because no marked difference in the inner layer oxide thickness was obvious, it is convinced that the magnetic

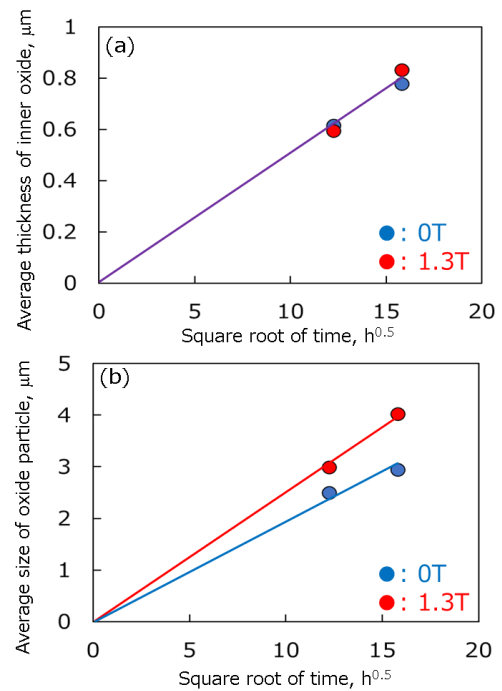


Fig. 2 Time dependencies of average thickness of (a) inner oxide and (b) outer oxide after corrosion tests under 0 T and 1.3 T.

field does not affect the corrosion reaction itself. Since the inner oxide was formed by the dissolution of metal ions and the penetration of oxygen, it is speculated that the amount of metal ions leached into the environment is also unchanged. By contrast, the difference in oxide particle size indicates that the magnetic field possibly affected the re-deposition of dissolved metal ions or the attachment behavior of oxides. Despite the limited conditions for impact on component design, if the amount of dissolved ions from the corrosion reaction remains unchanged and the precipitation originated by dissolved ions is continued, the corrosion allowance and the amount of activated corrosion product are expected to decrease.

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