

Corrosion Characteristics of FeCrW Model Alloys in 360 °C High Purity Water

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1. Introduction

For the successful development of nuclear fusion power reactors, integrity of structural materials is one of the main concerns to solve. Many studies on the structural materials' properties like mechanical properties and compatibility with the coolant or other materials in operating conditions have been conducted until recently [1-8]. The main candidates for fusion power reactors' structural materials are Reduced Activation Ferritic/Martensitic (RAFM) steels. These iron-based RAFM steels are mainly composed of 8~9%Cr and 1~2%W, and RAFM steels replaced high activation minor elements from conventional FM steels with low activation elements like V, Ta, etc. [9].

Water is one of the main candidates for coolant of various fusion reactor designs. Studies on long-term corrosion properties in the high pressure and temperature of FM steels showed correlations with Cr concentrations. With reducing Cr concentration below 12%, the corrosion rate increased rapidly [10]. But considering the other mechanical properties like fracture toughness, it appears that the 9% Cr is the most promising Cr concentration [11]. Although RAFM steels are quite vulnerable to PWR conditions due to low Cr concentration, it seems that water-cooled components of RAFM steels can be safely operated, at least under proper coolant chemistry control [12].

In this study, we made FeCrW model alloys for long-term corrosion testing as a function of water chemistry conditions. As the first step, we have investigated long-term corrosion properties of two model alloys in stagnant 360 °C high purity water conditions.

2. Literature Data Analysis

Before conducting corrosion tests, we collected weight change data from prior studies conducting corrosion tests with RAFM steels or other FM steels, as shown in Fig. 1 [1-8]. It shows that as the test temperature becomes higher, the weight change becomes higher. It also appears that as the test temperature is higher, overall weight gain behavior follows the parabolic law more closely. Under flowing water conditions, the weight loss has been observed. It is not clearly shown in Fig. 1, but the weight loss seemed to be suppressed as the dissolved oxygen (DO) concentration of the flowing water becomes high [8].

Figure 2 shows the corrosion test conditions that had been reported on the prior studies. The Cr concentration varied from 8 to 12 wt%, the test temperature ranges from ~220 to 550 °C, and the DO level varies from deaerated to fully aerated condition (~8 ppm). Most of

earlier testing was conducted under a stagnant condition, but some flowing water data are available, which were conducted with the flowing water velocity of 1 or 5 m/s. This data analysis can help one identify which test conditions have sufficient data or which test conditions do not.

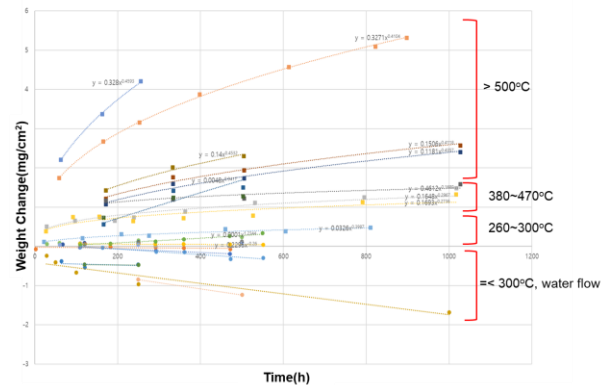


Fig. 1. Weight change results from prior corrosion tests studies of FM steels.

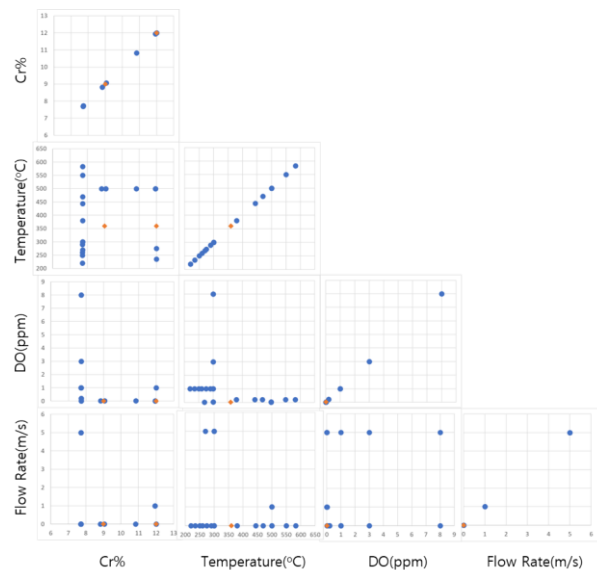


Fig. 2. Corrosion test conditions of prior studies. The Orange dots are the conditions of this study.

3. Experimental Methods and Results

3.1 Experimental procedure

The materials used in this study were two model alloys: Fe12Cr1W and Fe9Cr. The alloys were prepared by the arc melting and vacuum induction melting methods. Then, for the heat treatment, the ingots were first reheated to 1180 °C for 1 h, followed by the hot

rolling, which led to the thickness reduction to 1.6 mm. The hot rolling was finished at 670~680 °C. After air cooling to room temperature, normalizing was conducted at 980 °C for 0.5 h. Then, the plates were quenched in water. The final heat treatment or tempering was conducted at 760 °C for 1.5 h, followed by air cooling to room temperature. The chemical compositions of each alloy obtained by spark optical emission spectrometer (Spark-OES) are shown in Table 1. Fe₉Cr₁W model alloy was also prepared but is planned for testing as a next step.

The static corrosion test was conducted in an autoclave. The specimens (10 x 10 x 1.5 mm³) were all mirror finished by polishing with 1 μm diamond paste. The corrosion tests were conducted at 360°C with the pressure of 17.8 MPa deaerated high purity water. The corrosion tests were performed under testing time ranging from 50 h to 500 h. The weight of specimens was measured before and after corrosion tests using a precision balance. Corrosion products were examined on the specimen surface and cross-section using scanning electron microscopy (SEM), X-ray diffraction spectrometry (XRD). The corrosion rate was intended to measure with two different methods: weight change rate and dissolution rate of oxides.

Table I: Chemical composition of the alloys (Wt.%)

	Fe	Cr	W
Fe ₁₂ Cr ₁ W	Bal.	11.4	1.04
Fe ₉ Cr	Bal.	8.8	-
Fe ₉ Cr ₁ W	Future Work		

3.2 Weight change

Figure 3 shows the weight change of specimens after corrosion test at 360°C for up to 300h. All of the specimens gained weight after corrosion tests. The Fe₁₂Cr₁W and Fe₉Cr specimens did not show the difference on weight change tendency.

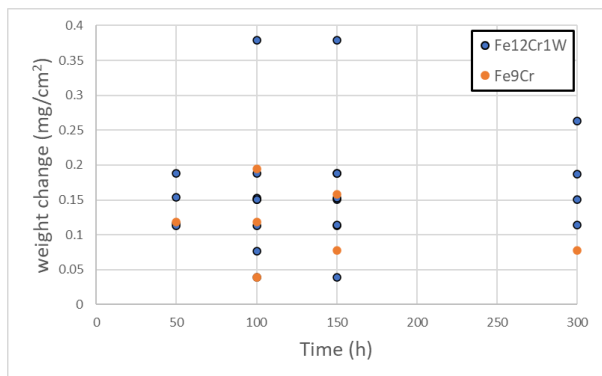


Fig. 3. Weight change of Fe₁₂Cr₁W and Fe₉Cr specimen plotted as a function of time.

3.3 Surface morphology

Figure 4 shows the SEM secondary electron (SE) images of specimen surface after corrosion testing. The block like oxide crystals are observed on the surface of specimens with the higher magnification. After the 100-h exposure testing, two model alloys showed no significant difference in the surface oxide morphology. However, it is expected that longer exposure may reveal the effect of Cr concentration on the surface oxide or overall corrosion behavior.

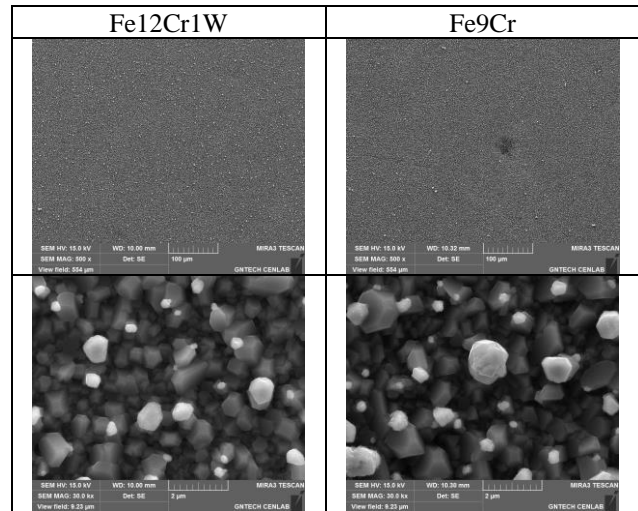


Fig. 4. Surface SE image of the Fe₁₂Cr₁W(left) and Fe₉Cr(right) after corrosion test for 100 h.

4. Conclusions and Future Work

The long-term corrosion testing was conducted in 360 °C deaerated water with two model alloys: Fe₁₂Cr₁W and Fe₉Cr. The 1~2 μm oxide crystals were observed on the oxidized specimen surfaces. The 100-h exposure testing results revealed no significant difference in the model alloys. It is expected, however, that the longer exposure may show the effect of Cr concentration on the surface oxide morphology or overall corrosion behavior.

The longer-term corrosion testing is currently in progress. Fe₉Cr₁W alloy will also be tested and compared with two other model alloys. For all three alloys (Fe₉Cr₁W, Fe₁₂Cr₁W, Fe₉Cr), the long-term corrosion testing with a high DO concentration (DO 1ppm) is also planned.

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