Oxidation Behavior of Fe-based Alloy under Normal Operation and Accident Conditions

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1. Introduction

Recently, interest in using FeCrAl alloy as the nuclear fuel cladding material in conventional light water reactors (LWRs) has increased considerably. This is because its superior oxidation resistance at high temperatures could significantly reduce the risk of explosions caused by hydrogen gas, as was the case in the Fukushima nuclear reactor accident [1]. Other superior properties of FeCrAl alloy are excellent formability and very good high strength at high temperature. For these reasons, Fe-based alloy is considered as one of the most promising candidates for accident tolerant fuel material.

The integrity of the fuel cladding should be maintained not only during normal operation but also in a postulated design-based accident. Therefore, it is necessary to understand clearly the oxidation behavior of candidate materials under both normal operation and loss-of-coolant accident (LOCA) condition for their application to the fuel cladding material in LWRs.

In this study, long-term corrosion and high temperature oxidation behaviors were investigated in a corrosion environment simulating pressurized water reactor and simulated LOCA condition.

2. Methods and Results

In this section some of the techniques used to study oxidation behavior of FeCrAl alloy and highlight data obtained are described.

2.1 Corrosion Test

Corrosion tests of the FeCrAl alloy specimens were performed in the corrosion environments which simulated the conditions encountered during normal PWR operation using the static autoclave. Ar gas bubbling was performed to reduce the oxygen content in the water prior to the corrosion test. Temperature and pressure of autoclave were 360°C and 18.5 MPa, respectively. The pH of water was measured to vary between 7.0 and 7.5. Maximum duration days were 320 days. The weight change of the FeCrAl specimens was measured periodically using a microbalance with an accuracy of 0.1 mg. The surface oxide of corroded specimen was observed using a scanning electron microscopy (SEM), transmission electron microscopy (TEM), X-ray diffraction (XRD) analysis.

2.2 High Temperature Oxidation Test

FeCrAl alloy samples were oxidized at 1200 and 1300°C for up to 3000s. Thermo-gravimetric analyzer (TGA) and a radiant heating furnace incorporating infrared lamps and a quartz chamber that simulates real LOCA conditions were used to conduct the high temperature oxidation tests. Following introduction of steam into the chamber, furnace heating started for a pre-test hold temperature of 300℃. Steam flow and 300℃ of sample temperature were stabilized within 180 s. After stabilization process, temperature of specimen was rapidly increased to target temperature within 120s. The atmospheric pressure in the test chamber was maintained at 1 atm or slightly above 1 atm. The average steam flow rate was about 5 mg/cm^2•s. The oxidized SiC samples were weighed after each oxidation test. The surface morphology of the oxide layer was investigated using field-emission SEM. A microstructural analysis was carried out using high resolution TEM (HRTEM.) at 300 kV and XRD. To determine the valences of the ions in the oxide layers, an XPS study was conducted. Peak fitting of the XPS spectra was performed using OriginPro7.5.

2.3 Oxidation Behavior of FeCrAl Alloy under Normal Operation Condition.

To compare the corrosion behavior of FeCrAl alloy and existing Zr-based alloys, their weight gain obtained from water static autoclave tests is presented in Fig. 1. FeCrAl alloy showed extremely low weight gain compared to Zr-based alloys. Weight gain of FeCrAl specimens up to 150 days test was less than 1 mg/dm^2. On the contrary, Zr based alloys showed almost 100 1 mg/dm^2 in their weight gain. The oxide scale formed on the surface of FeCrAl sheet sample during corrosion test was analyzed by TEM and EDS measurement and shown in Fig. 2. For microstructural characterization, additional XRD analysis was carried out. The morphology of oxide layer was uneven and its thickness was not more than 500 nm. EDS and XRD analysis indicates that Fe_2O_3 was formed durind 360°C test.

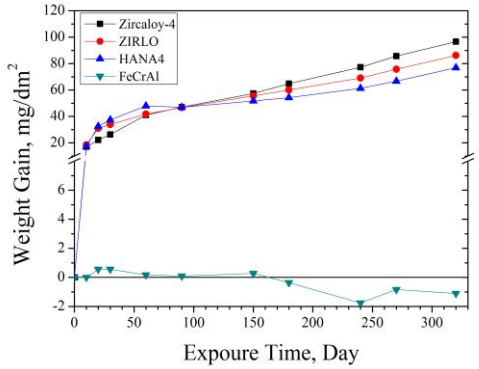

Fig. 1. Corrosion behavior of the FeCrAl alloy in 360C water.

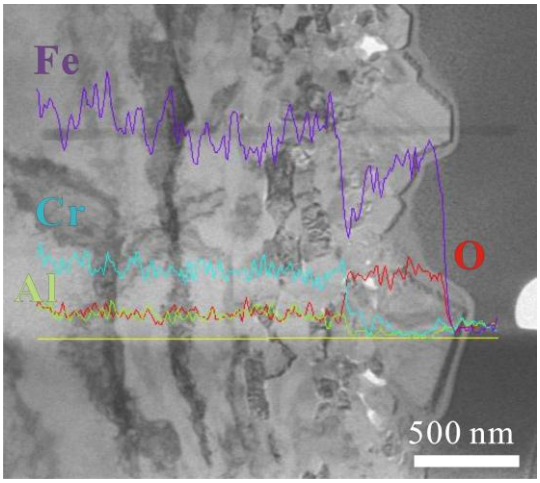

Fig. 2. Cross-sectional TEM image and EDS measurement from alloy matrix to oxide layer.

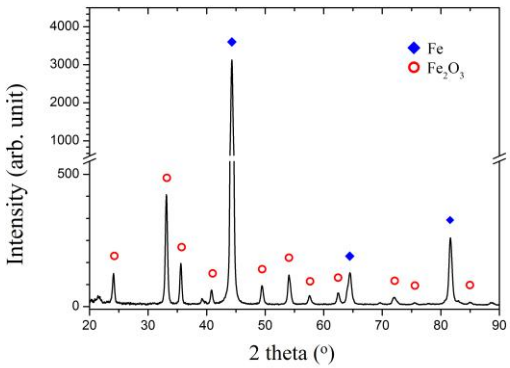

Fig. 3. XRD analysis obtained from corroded FeCrAl alloy specimen.

2.4 Oxidation Behavior of FeCrAl Alloy under Accident Condition

To investigate oxidation resistance of FeCrAl alloy, high temperature oxidation tests were carried out under steam environment. Fig. 4 shows the weight gain behavior of FeCrAl alloy oxidized at 1200°C for up to 3000s. FeCrAl showed only 60 in their weight gain after exposure time of 3000s. It is just 1.8 % compared with that of Zircaloy-4 sample. Oxide formed during high temperature oxidation test was analyzed by XRD measurement. Fig. 5 shows the result. It was revealed that grown oxides is alumina layer. This result is not consistent with that obtained from 360℃ test.

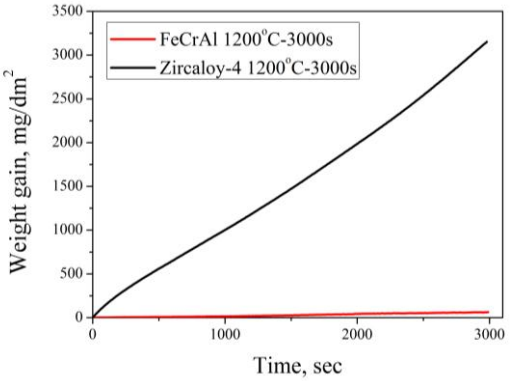

Fig. 4. Weight gain of FeCrAl and Zr alloys during high temperature oxidation test with TGA.

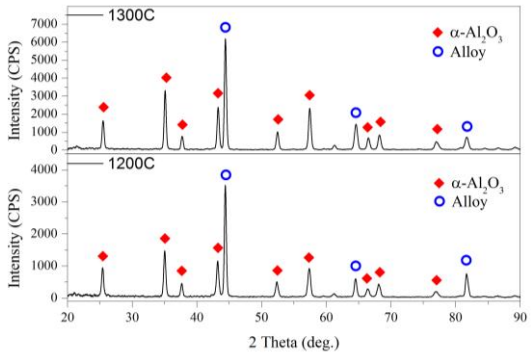

Fig. 5. XRD analysis obtained from FeCrAl alloy specimens oxidized at 1200 and 1300°C.

3. Conclusions

Oxidation tests for FeCrAl alloys samples were carried out under normal and accident conditions. It was observed that oxides grown during the test show differences in their chemical properties and micro structure. Fe_2O_3 oxide was grown in water static test at 360℃ while alumina was observed in high temperature oxidation test.

ACKNOWLEGEMENT

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[1] T. Tsuruda, Nuclear power plant explosions at fukushima-daiichi, Procedia Eng. Vol. 62, p. 71, 2013