Oxidation Resistance Evaluation of FeCrSi alloy in High Temperature Steam Environment

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1. Introduction

In severe nuclear power plant accidents, similar to the Fukushima accident, the zirconium alloy fuel cladding can be a source of hydrogen, which can lead to hydrogen explosion. To solve these problems, development of accident tolerant fuel (ATF) cladding has been performed in many countries [1-2]. Massachusetts Institute of Technology (MIT) proposed a new concept for the ATF cladding design. This ATF cladding is multi-metallic layered composite (MMLC) fuel cladding. The MMLC fuel cladding is mainly consisted of zirconium alloy and FeCrSi alloy. The inside layer is composed of zirconium alloy that has low neutron absorption cross-section and high neutron irradiation resistance. The outside layer is composed of FeCrSi alloy, of which the oxidation resistance has been proven in liquid lead-bismuth [3]. In this study, we conducted high temperature oxidation testing at 1200℃ steam environments in order to evaluate the high temperature oxidation resistance of FeCrSi alloys.

2. Experimental Methods

In order to conduct the high temperature oxidation testing, specimens of Zr-Nb-Sn alloy as a reference and FeCrSi alloys were prepared. FeCrSi alloys of 30 × 20 × 2 mm coupons of three different compositions were prepared. The composition of FeCrSi alloys is shown the Table I.

Table I: Composition of FeCrSi alloys

	Elements (wt%)		
	Fe	Cr	Si
Fe12Cr2Si	Bal.	12.08%	1.98%
Fe16Cr2Si	Bal.	16.06%	1.98%
Fe20Cr2Si	Bal.	20.06%	1.95%

The oxidation tests were conducted referring to NRC Reg. guide DG-1262[4]. In these tests, the resistance heating tube furnace was used. To prevent the generation of condensate water, steam and Ar gas were supplied at 500 cc/hr after heated to 350℃. In order to increase the heating speed of a specimen, after furnace was heated and stabilized, the specimen was inserted in furnace. After the specimen was oxidized at 1200℃ for about 100 secs, it was taken out of the furnace. The temperature profile of the specimen is shown the Fig. 1.

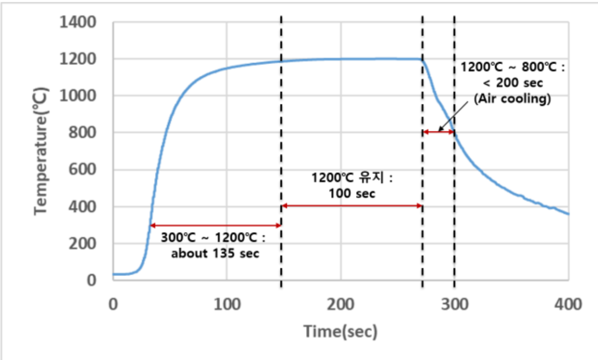


Fig. 1. The temperature profile of the specimen during the oxidation testing

3. Results and Discussion

After conducting the high temperature oxidation test, the analysis for the weight-gain and the oxide layers was conducted to evaluate the oxidation resistance.

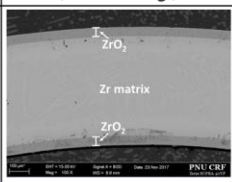
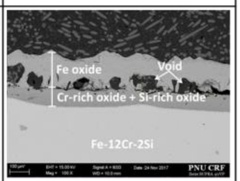
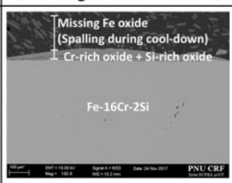
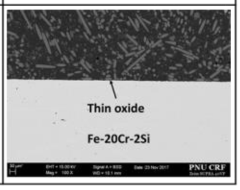
Specimen	Ref. Zr-Nb-Sn alloy	Fe12Cr2Si
Weight-gain (mg/cm^2)	10.07 (3 times avg.)	15.71
SEM (x100)		
Specimen	**Fe16Cr2Si**	**Fe20Cr2Si**
Weight-gain (mg/cm^2)	-29.60 (Missing outside oxide)	0.23
SEM (x100)		

Fig. 2. Comparison of oxidation resistance of Ref. Zr-Nb-Sn alloy and FeCrSi alloys

The weight-gain results in Fig. 2 showed that Fe12Cr2Si has higher weight gain than Zr alloy despite the loss of some outside oxide and the outside oxide layer of Fe16Cr2Si alloy is missing during cool-down. Therefore, the oxidation resistance of Fe12Cr2Si and Fe16Cr2Si alloys seems to be poor. However, Fe20Cr2Si alloy shows excellent oxidation resistance. In Fig. 2, Fe20Cr2Si alloy shows a very thin oxide layer and very low weight-gain.

In order to determine the oxide composition of each specimen, Energy Dispersive X-ray Spectroscopy (EDS) analysis was conducted for each specimen.

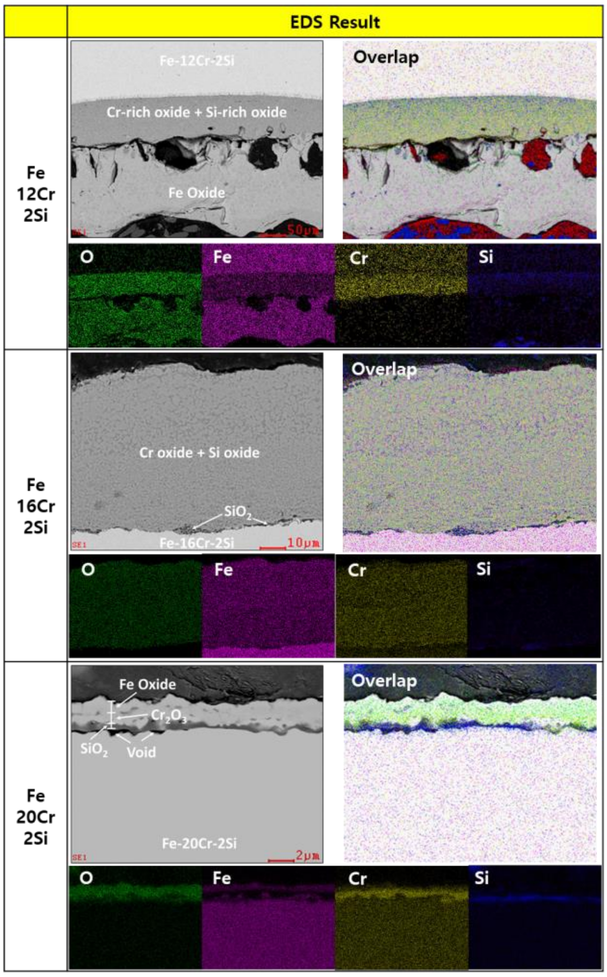


Fig. 3. EDS results of FeCrSi alloys

In Fig. 3, it is observed that Si-rich oxide, Cr-rich oxide, and Fe oxide layer appear in sequence from the base matrix. As a Cr content in the specimen increased, it is observed that each oxide layer was clearly separated. The Cr-rich oxide in Fe20Cr2Si is not likely to include Fe elements, but the Cr-rich oxide in Fe12Cr2Si and Fe16Cr2Si appears to include Fe element. In the previous study, it is known that $FeCr_2O_4$ can be formed when Fe and Cr are present at 1200℃, which is known to have poor oxidation resistance [5]. Therefore, the Cr-rich oxide in Fe20Cr2Si is predicted to be Cr_2O_3, and the Cr-rich oxide in Fe12Cr2Si and Fe16Cr2Si is predicted to be the Fe-Cr compound oxide such as the $FeCr_2O_4$. As the Cr content in specimens increased, it is observed that Si oxide area increased at the oxide/metal interface.

Especially, the continuous thin Si oxide layer is observed at the metal-oxide interface in Fe20Cr2Si alloy. It is thought that this continuous Si oxide layer at metal-oxide interface prevents the oxidation of base metal.

4. Conclusions

The high temperature steam oxidation testing showed that the oxidation resistance of Fe12Cr2Si alloy and Fe16Cr2Si alloy is not as good as Zr-Nb-Sn alloy in 1200℃ steam environments. However, it is observed that Fe20Cr2Si alloy has excellent high temperature oxidation resistance. It is thought that the continuous Si oxide layer prevents the oxidation of base metal. It is concluded that the Fe-Cr alloy with 2 wt% Si does not have sufficient oxidation resistance in the early stage when the Cr content is not higher than a certain level (16~20wt%).

ACKNOWLEDGEMENT

This work was financially supported by the International Collaborative Energy Technology R&D Program (No. 20168540000030) of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) which is funded by the Ministry of Trade Industry and Energy and was supported by “Human Resources Program in Energy Technology” of the Korea Institute of Energy Technology Evaluation and Planning (KETEP), granted financial resource from the Ministry of Trade, Industry & Energy, Republic of Korea. (No. 20164010201000).

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