Oxidation resistance improvement mechanism of Si in FeCrSi alloy at high temperature steam environment

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1. Introduction

In order to prevent the severe accident of nuclear power plants, many ATF (Accident-tolerant fuel) cladding concepts have been proposed in the world, such as coated Zr alloy, FeCrAl, SiC, Cr-Mo alloy etc. [1-2]. Multi-metallic layered composite (MMLC) cladding is one of the potential ATF cladding designs. It is consisted of zirconium alloy, FeCrSi alloy and buffer materials in between them. Among these materials, the FeCrSi alloy is located at the outermost part of MMLC and responsible for oxidation protection. In our previous study, the Fe20Cr2Si alloy has been proven to maintain excellent resistance in steam-Ar environment until 24 hr. Furthermore, the high temperature oxidation resistance of FeCrSi alloys shows different characteristics depending on the Cr content [3-5]. Also, previous study showed that the addition of Si increases the oxidation resistance [5-6]. However, the detail oxidation prevention mechanism with increasing Si content in a high-temperature steam environment is not known precisely. In order to check the detail mechanism, we analyzed metal-oxide interface after high temperature oxidation test.

2. Purpose and method of analysis

In the previous study, we observed the generation and growth of nodular oxide in the low Si content FeCrSi alloy, Fe20Cr and Fe20Cr1Si, after high temperature oxidation test. On the other hand, nodular oxide was not found in the high content Si alloy, Fe20Cr2Si until 24 hr test. Also, when comparing Fe20Cr and Fe20Cr1Si, the time of nodular oxide generation was slower in Fe20Cr1Si [5]. In this result, we predicted that the addition of Si has the effect of preventing the formation of nodular oxide. In order to detail nodular oxidation prevention mechanism with increasing Si content, we analyzed metal-oxide interface where the generation of nodular oxide is expected to begin in the initial stage of oxidation using FIB (Focused Ion Beam). It was predicted that nodular oxide would be generated in the area where the oxide was swollen and cracked, we intensively observed this area. Figures 1 show the FIB analysis area of specimen surface and the chemical composition of FeCrSi specimens is shown in Table I.

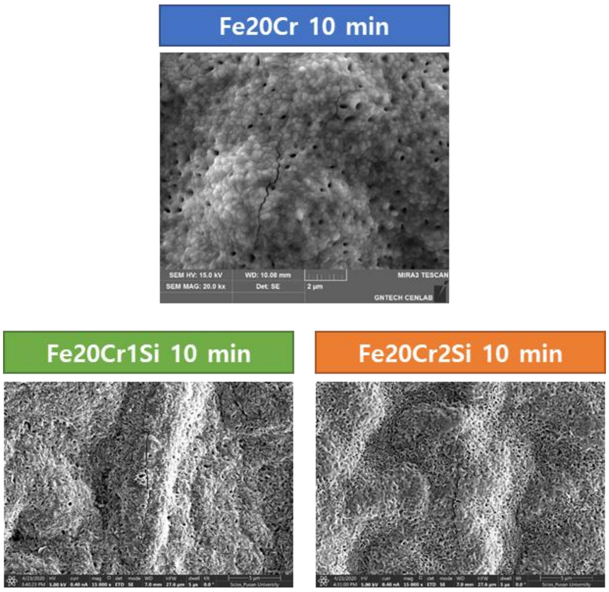

Fig. 1. The FIB analysis area of specimen surface

Table I: Chemical composition of FeCrSi specimens

	Fe	Cr	Si	Method
Fe20Cr	Bal.	20.42	0.00	LIBS
Fe20Cr1Si	Bal.	20.39	1.14	LIBS
Fe20Cr2Si	Bal.	20.06	1.95	DCP-AES

3. Results and Discussion

In order to observe the metal-oxide interface, it is conducted SEM-EDS analysis after the FIB milling in Figure 1 area. Figures 2 show the SEM-EDS results of Fe20Cr 10 min test specimens after FIB milling and tilting.

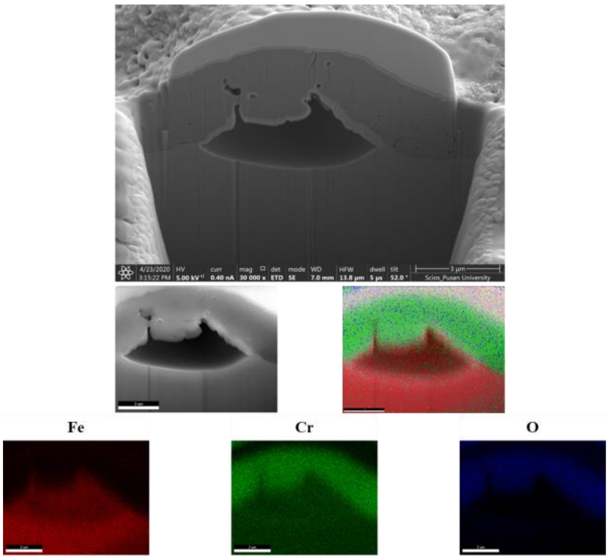

Fig. 2. EDS mapping results on the cross-sectional images after FIB milling of Fe20Cr in 10 min test

In Figure 2, it is observed that the cavity exists in metal-oxide interface of Fe20Cr specimen and the oxide is Cr oxide. Figures 3 and 4 show the SEM-EDS results of Fe20Cr1Si and Fe20Cr2Si 10 min test specimens after FIB milling and tilting.

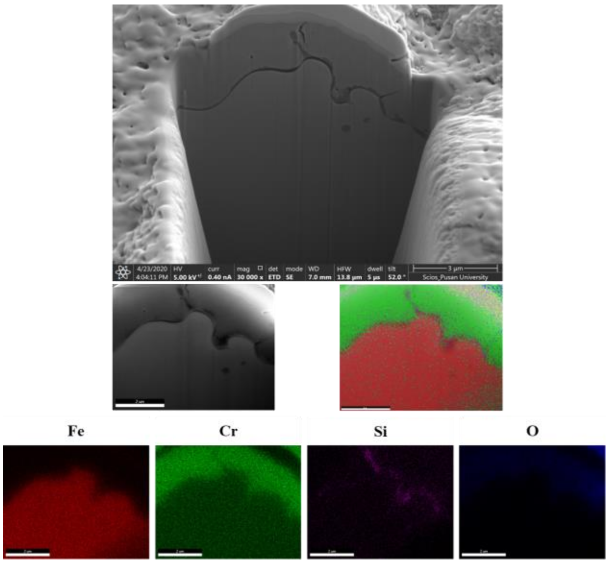

Fig. 3. EDS mapping results on the cross-sectional images after FIB milling of Fe20Cr1Si in 10 min test

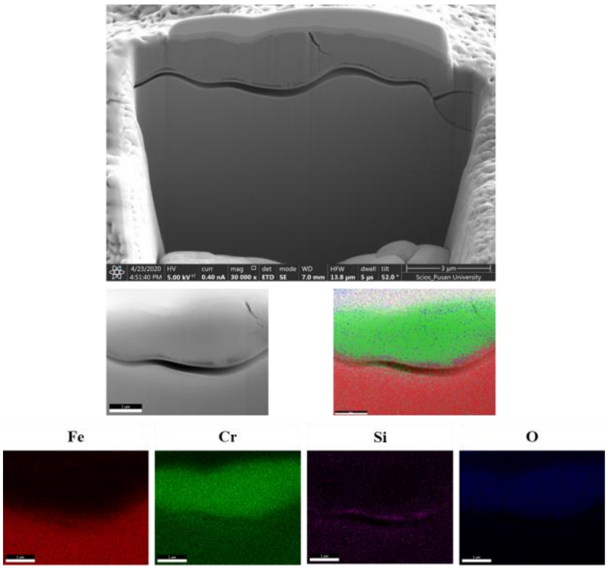

Fig. 4. EDS mapping results on the cross-sectional images after FIB milling of Fe20Cr2Si in 10 min test

In Figs. 3 and 4, the cavity is not observed in metal-oxide interface of Fe20Cr1Si and Fe20Cr2Si specimens. The oxides are consisting of Cr oxide and Si oxide. If the cavity produces in metal-oxide interface, the oxide is swelling and the cracks are easily produced due to stress concentration. In addition, the oxygen can easily penetrate into the oxide along the crack, thus the probability of nodular oxidation occurrence can increase. In this result, it is predicted that Si addition in FeCr alloy prevents the generation of cavity in the metal-oxide interface. It is thought that Si effect of preventing formation of nodular oxide is due to the effect of preventing generation of cavity.

4. Conclusions and Future Work

This study observes the metal-oxide interface after high temperature oxidation test in order to check the detail oxidation prevention mechanism with increasing Si content. In the Fe20Cr specimen, the cavity was observed in metal-oxide interface. However, in Fe20Cr1Si and Fe20Cr2Si specimens, the cavity was not observed in metal-oxide interface. If the cavity exists in metal-oxide interface, the oxide is swelling and cracks can easily produce in oxide. The cracks reduce oxidation resistance and can lead to nodular oxidation. It is thought that the addition of Si in the Fe-Cr alloy prevents the generation of cavity and thus prevents nodular oxidation. In order to check the detailed cavity generation prevention mechanism of Si, it is needed to conduct additional analysis.

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