Basic Study on the Development of a Metal Cladding with Protective SiC Composites

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1. Introduction

In the field of nuclear plant safety analysis, various low probable accidental situations may result in fuel rod exposure. After the Fukushima accident, there has been a rising need to develop nuclear fuel that can, in case of a severe accident, minimize the violent reactions between the cladding and water steam and prevent hydrogen explosions. For that reason, ceramic coating on metal has been an interest in nuclear society. Nuclear fuel with protective SiC composites has a noticeably high ability to prevent explosions, and the metal cladding prevents the discharge of volatile nuclear fission products. Also, the interior metal cladding can make up for the brittleness of the SiC composites. The goal of this study is to manufacture a metal cladding with protective SiC composites by a low-temperature process and to inspect its oxidation resistivity.

2. Experimental

2.1 Specimen Preparation

The specimens used in this study are Zry-4 tubes used in commercial nuclear power plants. Table 1 shows the chemical composition of the specimen. Cladding tubes were cut to the height of 20mm~22mm, They were cleaned and etched.

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Table 1.chemical composition of Zry-4

	Zr (wt%)	Nb (wt%)	Sn (wt%)	Fe (wt%)	Cr (wt%)
Zry-4	bal.	-	1.35	0.2	0.1
Zirlo	bal.	1.0	1.0	0.1	-

Four kinds of specimens were made. Cladding with SiC coating using PCS, cladding with protective SiC composites made by PCS, cladding with SiC coating using PVD, cladding with protective SiC composites made by PVD.

In this study, cladding with protective SiC composites made by PCS is the only specimen that had been tested

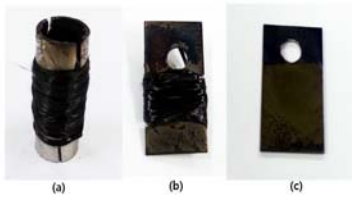


Figure 1. (a) Cladding with protective SiC composites made by PCS, (b) Cladding with protective SiC composites made by PVD. (c) Cladding with SiC coating using PCS

2.2. Materials

Hydrido Polycarbosilane (HPCS) was supplied by Starfire System. co., and it' s chemical structure is shown in figure. 2. The coating solution was prepared as 20wt% HPCS solution in toluene

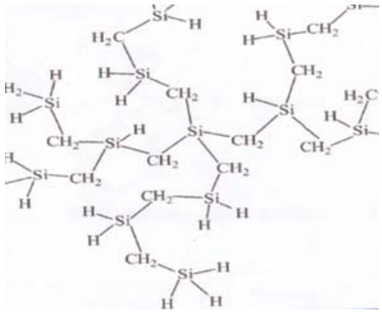


Figure 2. chemical structure of HPCS

The fiber used in this study was supplied by UBE-Korea. The grade of this fiber is ' S' and the composition of this fiber is $Si_1C_{1.4}O_{0.4}Ti_{0.03}$. The diameter of this fiber is about 7 ㎛.

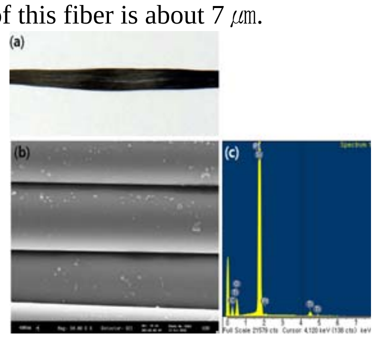
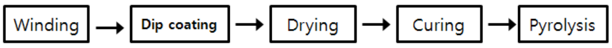


Figure 3. (a) One strand of the SiC fiber, (b) SEM image of the SiC fiber (C) EDX result of the SiC fiber

2.3. Coating process



SiC fibers were wound by 1 line thickness or 4 lines thickness as shown in Figure. 1. After winding, the specimen was dipped into the precursor for 24 hours and were dried for 24 hours at room temperature. The coated specimen were cured at 150℃ for 60 minutes in O2 atmosphere. Pyrolysis was proceeded at 700C in argon atmosphere to derive SiC film.
The coating was done on half of the specimen to compare with metal layer and coated layer.

2.4. Steam oxidation test

The apparatus for the high-temperature steam testing of the coated Zirconium alloys used in this study is shown in Figure 4. In the tube furnace, there is an alumina tube in the center and the heater is surrounding the tube. In the case of steam experiment was established steam bubbler. Also an argon gas was supplied to the bubbler for steam generation. The furnace maintained at fixed temperatures i.e., 1200C, and we put the specimens at the center of the tube. After 10 minutes passed, the specimens were pulled out. After the experiment the specimen was ground and polished. The microstructures of the polished surface of the specimen were observed by an optical microscope.

Figure 4. Apparatus (tube furnace) for high temperature oxidation of coated Zr alloys in steam

3. Result

Figure 5 shows that metal layer has been more oxidized than the coated layer

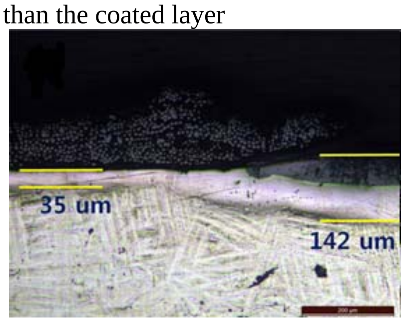


Figure 5. 4 line thickness specimen

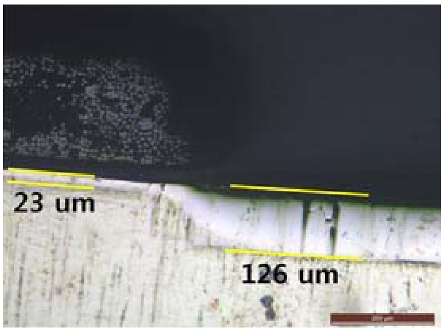


Figure 6. 1 line thickness

Figure 5 and Figure 6 shows that coated layer part have been defended the oxidation more than metal layer. Normally, when oxidizing the Zry-4 cladding at 1200℃ in steam for 10 minutes, the oxide thickness is at least 120um.

The reason of the ability of defending the oxidation is the SiC composites prevent the steam which is trying to break in.

Table 2. Suppression ratio of the specimen

Suppression ratio =	$\frac{\text{Metal layer oxide thickness}}{\text{Coated layer oxide thickness}}$
1 line thickness	$\frac{24\ \mu m}{126\ \mu m} = 0.19$
4 line thickness	$\frac{27\ \mu m}{142\ \mu m} = 0.19$

4. Conclusions

Cladding with protective SiC composites made by PCS had a very high oxidation resistance. The oxide thickness was less than 20% compared to uncoated Zry-4. This study builds a necessary foundation for future research on protective SiC composites that can possibly develop nuclear fuel that contains " inherent safety' .

But still need more study in corrosion test in normal state and gamma ray exposure.

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