Cr-Al composite cladding prepared by swaging and electroplating

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1. Introduction

Nuclear fuel cladding is an important key material that directly affects nuclear power plant efficiency and safety. It effectively transfers the heat generated by the nuclear fission reaction of nuclear fuel to the coolant while preventing fuel and fission products from leaking into the coolant. Therefore, it is very important to select a sheath material having high corrosion resistance and mechanical properties suitable for a coolant when irradiating high pressure, high temperature, and neutrons. Zirconium alloys have shown high potential as cladding materials due to their low neutron absorption under extreme conditions, high corrosion resistance and good mechanical properties. However, the zirconium alloy was found to have poor physical and chemical properties at high temperature and high pressure conditions exceeding 1000 ℃ at the time of the 2011 Fukushima nuclear power plant accident [1]. The need for research on the development of ATF (accident tolerant fuel) cladding with improved physicochemical stability was emphasized after the Fukushima nuclear power plant accident [2-3]. It was difficult to fabricate several meter long cladding with coating processes that have been previously studied. In this study, in order to overcome the disadvantages of coating, SiC composite, and FeCrAl alloy [4-6], a swaging process capable of uniformly modifying the surface at room temperature was applied. First, Cr was plated on the Al exterior to select mechanically and chemically stable external materials at high temperatures. Second, the ATF clad tube was fabricated by swaging the Cr-plated Al tube on the outside of Zircaloy-4 tube (PST: pseudo single tube). Finally, heat treatment was performed at temperatures of 600, 900, and 1200 ℃, and the properties were analyzed to prove superior performance compared to the existing Zircaloy-4.

2. Methods and Results

2.1 Plating and swaging process

A 30 μm -thick Cr film was formed on the outside of the Al tube (outer diameter: 11.09 mm, inner diameter: 10.79 mm length: 1 m) by electroplating. As the inner tube, a Zircaloy-4 sheathed tube (outer diameter: 9.57 mm, inner diameter: 8.30 mm, length: 1 m) was used, and a double tube was prepared by inserting a Zircaloy-4 tube into a Cr plated Al tube. The inside of the Zircaloy-4 tube was completely filled with water-soluble KNO_3 powder, which generates a force of reaction against the force acting from the outside to the center during the swaging process. The swaging process applied a pressure of 4 t/cm^2 toward the central axis of the double pipe through the rolling process. The inner surface of the outer tube and the outer surface of the inner tube are brought into close contact with each other due to the compressive stress applied during the axial pipe process and the tensile force applied in the longitudinal direction to cause strong adhesion. In addition, the thickness, inner diameter and outer diameter and length of the final tube can be adjusted according to the number of times the swaging process is performed. Fig. 1 shows the images of the manufacturing process and the physical role of KNO_3 filler in the swaging process.

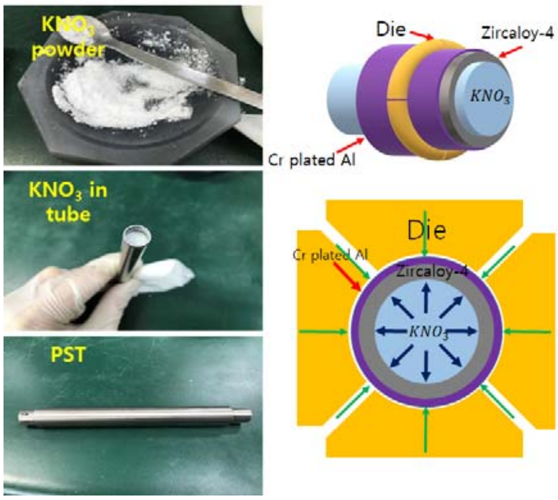

Fig. 1. The images of the manufacturing process and the physical role of KNO_3 filler in the swaging process.

The uniformity of the interface of the PST was confirmed by SEM image of the metal interface as shown in Fig. 2. It should be noted that the gap in the interface can degrade the mechanical and chemical properties of the tube. Interfaces without three-dimensional defects such as gaps or voids are less oxidized. Therefore, mechanical and chemical decomposition occurred less even in a high temperature or corrosive environment. The PST is manufactured at room temperature without applying heat using only physical force. Nevertheless, it is possible to make two different metals into one metal.

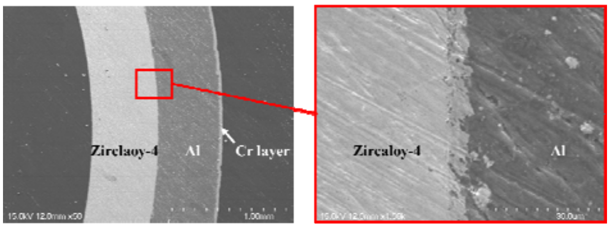

Fig. 2. SEM images of the interface after swaging Cr plated Al / Zircaloy-4.

Fig. 3 shows the SEM image of the Cr plating layer after Cr plated Al / Zircaloy-4 swaging. The thickness of the plating layer is about 30 µm, and it can be seen that the plating layer is very smooth by applying physical force through the swaging process. In order to analyze the uniform plating film, it is planned to proceed further with high magnification SEM and TEM.

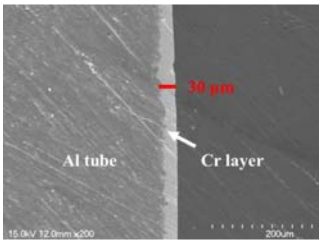

Fig. 3. SEM image of Cr plating layer after swaging Cr plated Al / Zircaloy-4.

Table 1 shows the size of the tube before and after the swaging process. It can be seen how the outer diameter and inner diameter decrease after swaging. Since the PST is manufactured by applying physical force, it is inevitable to reduce the outer diameter and inner diameter.

Table 1. Outer diameters and inner diameters of before and after Zircaloy-4 and Cr plated Al swaging.

	Zircalory -4	Cr plated Al	PST
Outer diameter	9.57 mm	12.01 mm	10.69 mm
Inner diameter	8.30 mm	10.79 mm	8.29 mm

2.2 Heat treatment

In order to evaluate the thermal stability of PSTs prepared using a swaging process at room temperature, experiments in which the PSTs were rapidly cooled after exposure to high temperatures were performed. Fig. 4 shows appearance of single Zircaloy-4, Al / Zircaloy-4 and Cr plated Al / Zircaloy-4 after 600, 900 and 1200℃ heat treatment.

Single Zircaloy-4 tube is stable at 600℃ and surface oxidation occurs at 900℃. In addition, at 1200℃, the shape collapsed due to thermal damage. Al / Zircaloy-4 tube shows a stable state at 600℃, but the shape is severely collapsed from 900℃. Since the melting point of Al is 660℃, this phenomenon is a natural result. Cr-plated Al / Zircaloy-4 tube shows a different tendency than Al / Zircaloy-4 tube. In other words, it maintained a relatively intact shape even at a temperature of 900℃, and maintained a more intact shape than the single Zircaloy-4 tube even at a temperature of 1200℃. This is expected to be the result that the Cr layer plated on the Al tube played a major role.

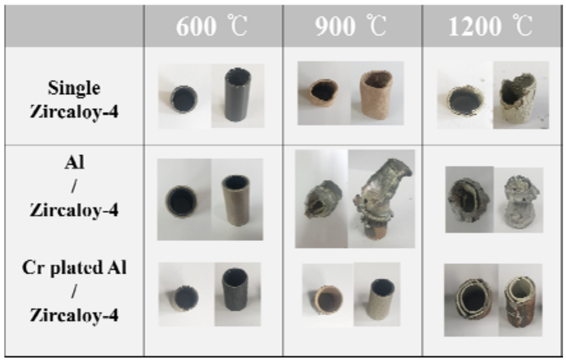

Fig. 4. Appearance of single Zircaloy-4, Al / Zircaloy-4 and Cr plated Al / Zircaloy-4 after 600, 900 and 1200 ℃ heat treatment.

Fig. 5 shows a graph of weight change after heat treatment of a single Zircaloy-4 and Cr plated Al / Zircaloy-4. Both tubes were stable up to 600℃ without any change in weight. At 900℃, both tubes had an increase in weight, and the weight change of Cr plated Al / Zircaloy-4 tube was less than that of Zircaloy-4 tube. This is expected to be due to the high temperature oxidation resistance of the Cr layer. Cr plated Al /Zircaloy-4 tube showed more stable results even at 1200℃.

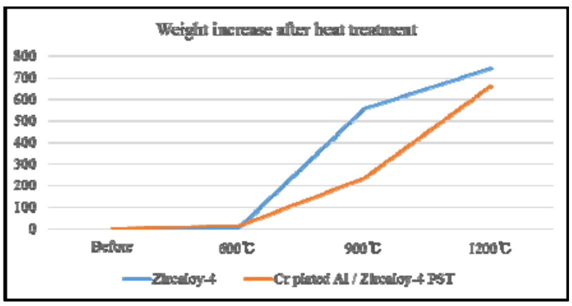

Fig. 5. Weight increase of single Zircaloy-4 and Cr plated Al / Zircaloy-4 after heat treatment.

3. Conclusions

This study suggests that an ATF cladding having a dual structure can be manufactured by a simple method through the 'Swaging process'. The Swaging is a room temperature process and there is no length limitation. Therefore, the application of the process is easy and can be manufactured very stably when applied to the cladding tube of 4 m or more in fact. In this study, a double cladding tube composed of Cr-plated Al tube and Zrircaloy-4 tube was fabricated at room temperature to increase the mechanical strength and oxidation resistance. In particular, Cr-Al is a validated candidate for ATF cladding. However, Cr-Al has properties that are difficult to manufacture in the form of a tube. Therefore, in this study, Cr was plated on Al exterior suitable for mass production, and Zircaloy-4 of the size used in commercial reactor was used for inner tube. The PST composed of two tubes had good interfacial conditions and adhesion, and showed superior high temperature oxidation resistance compared to Zircaloy-4 single tube.

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