Ionic Liquid Electroplating Technology to Prevent Inter-diffusion between Metallic Fuel and Clad Material

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1. Introduction

Sodium-cooled Fast Reactor (SFR) is used by high speed neutron. Due to recycling spent nuclear fuel, SFR is considered as next generation nuclear reactor [1]. Especially, U-Zr metal fuel in nuclear reactor has some characteristic such as ease of fabrication, high thermal conductivity, proliferation resistance and a good compatibility for sodium which have stimulated research in SFR for burning the long lived fission products. In spite of this advantage, metal fuel can be inconvenient to use. Actinide elements have a fuel-clad chemical interaction (FCCI) and eutectic reaction with Fe as nuclear cladding components at just above 650 ℃ [2]. Since nuclear cladding thickness is decreased during the combusting U-Zr metal fuel, the interaction place in the cladding is brittle and less strength. It is reported that the eutectic melting between U–Pu–Zr and Fe occurs above 650 ℃ [3]. Studies have been carried out in order to reduce FCCI behavior of metallic fuel in SFR reactors using an electroplating technique. Zirconium (Zr) and vanadium (V) thin layer onto a HT9 by using ionic liquid [4]. Zr and V thin film were deposited with various pH values (2, 5, 8) at 140 ℃ for 5hours. The result of diffusion couple tests at 660 ℃ for 25hours showed that the Zr and V thin films exhibited a barrier behavior for FCCI between the metal fuel and the clad.

2. Methods and Results

2.1 Specimen preparation

U–10 wt.%Zr and HT9 (Fe–12.0Cr–1.0Mo–0.6Ni–0.6Mn–0.52W–0.3V, etc. all values are wt.%) disks were used as fuel and cladding material to conduct diffusion tests. A diffusion couple test between Misch metal (70Ce-30La) and HT9 steel at 660 ℃ was And then a microstructural analysis was carried out. The diameter and thickness of the HT9 disks were 8 and 1.5 mm. Before the electroplating, the HT9 disks were polished with fine SiC paper. Zr thin film can be deposited on HT9 surface by electro-deposition as shown in Fig. 1. A Sargent bath consists of solution (Ethanol – ionic liquid (10, 20, 30%)), ionic liquid (1-Butyl-3-methylimidazolium chloride) and solute (Zirconium Chloride) [5]. A deposition of ionic liquid was conducted with power supply of 10 V at 50 ℃. During the electroplating, the solution was continually stirred by a magnetic bar. A schematic diagram of the electroplating apparent is presented in fig.1.

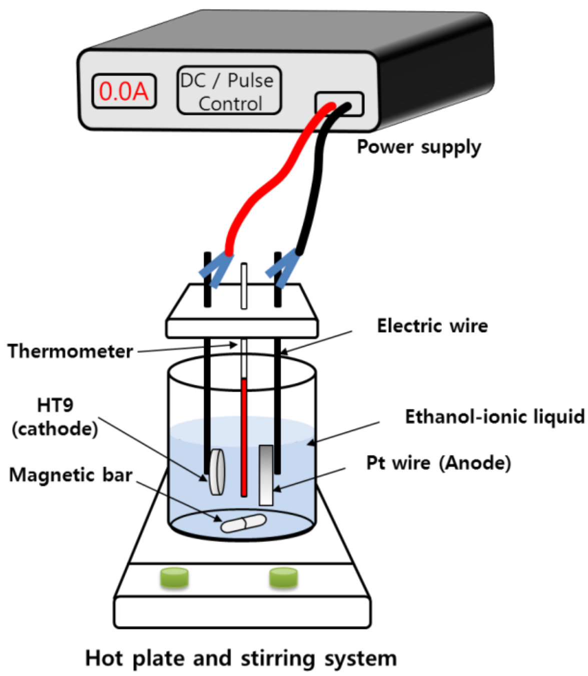


Fig. 1. A schematic illustration of a electroplating apparatus.

2.2 Diffusion couple test

In order to find out inter diffusion between the Misch metal and the HT9, the diffusion couple tests were carried out. Fig. 2 showed the schematic illustration of the diffusion jig. The Misch metal and Fe as cladding materials were used for contacting with each other. In an attempt to avoid needless reaction, the coupled specimen was wrapped with a tantalum foil. Prepared sample was inserted into jig and then the it was tightened. After clamping, it was encapsulated into quartz tube. The diffusion tests were performed at of

660 ℃ for 48 h. The temperature of 660 ℃ was chosen based on the general operation temperature of an SFR. After the heat treatment, specimens were cooled in an air. SEM and EDAX were conducted to investigate diffusion.

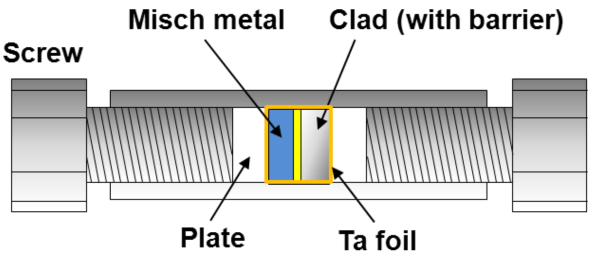
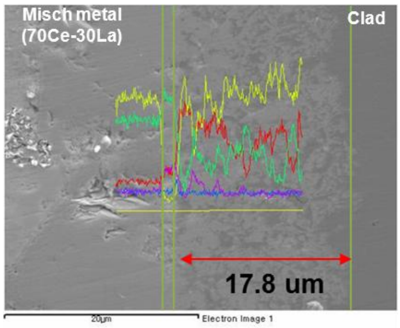


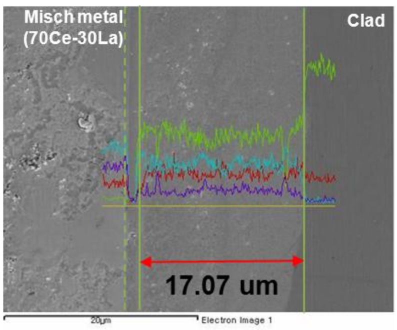
Fig. 2. Schematic illustration of the diffusion couple test.

3. RESULTS

Figure 3 shows the microstructure of the specimen after the diffusion couple test at 660 ℃. The thickness that (a)17.8 ㎛, (b)17.07 ㎛ and (c)118 ㎛ in the SEM indicates the initial interface implying that a reaction layer was formed between the Misch metal and the clad material. Even though ZrO_2 barrier could not block the Inter-diffusion between clad and metal fuel, barriers with ionic liquid concentration of 10 and 20 % could reduce the inter-diffusion between HT9 clad and misch metal.



(a)



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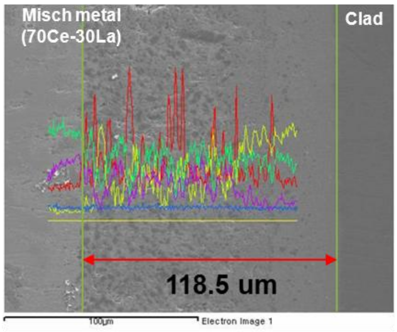

(c)

Fig. 3 Concentration profiles of Fe, Cr, La and Ce across the region of EDX analysis line at the interface between HT9 and misch metal. (a) 10% ionic liquid, (b) 20% ionic liquid and (c) 30% ionic liquid.

4. Conclusions

To prevent an FCCI between HT9 as cladding material and misch metal, electroplating of ionic liquid as a FCCI barrier on the surface of the HT9 was proposed. At a bath temperature of 50 °C, a Zr layer was plated at an applied voltage of 10V. Nevertheless, ZrO_2 barrier could not perfectly obstruct inter-diffusion, ionic liquid concentration of 10 and 20 % showed an increased performance.

Acknowledgements

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