

Electro-Deposition of Cr Layer to Prevent Fuel Cladding Chemical Interaction in Sodium Fast Reactor (SFR)

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1. INTRODUCTION

Disposal of high level nuclear waste is crucial problem in many countries that have nuclear plants. Small countries such as South Korea especially has limited disposal area and suffer from the continuously produced nuclear waste. A sodium cooled reactor (SFR) have attentions due to its capability to transmute nuclear waste.

In the core of a SFR, there are nuclear fuels and cladding. Unlike a conventional light water reactor, sodium reactors consider to use metallic fuels due to high thermal conductivity, great capability with sodium, and easier to fabricate [1]. Cladding is a important structural component that maintain the integrity of nuclear fuel and prevent fission product release, and transmit thermal energy to sodium coolant. Ferritic-martensitic steels are utilized for the cladding material. They have great swelling resistance up to 200 dpa, have high thermal conductivity, and low thermal expansion coefficient. HT9 has been adopted for the SFR research programs in many countries.

A crucial concern however is the reaction between actinide or rare earth elements in a metallic fuel and ferritic-martensitic steel cladding [2]. This phenomenon is named Fuel Cladding Chemical Interaction (FCCI). Lower melting point eutectic compounds are formed by this FCCI decreasing the integrity of cladding and nuclear fuel.

The coating of inner surface of FM steel cladding has been researched world widely to reduce FCCI. The coated layer acts as a diffusion barrier to actinide and rare earth elements. Various research teams use diverse coating methods and materials. Fauzia Khatkhatay et al., [3] performed pulsed laser deposition to coat TiN and ZrN on the surface of cladding. They performed Fe/Ce diffusion couple tests. TiN and ZrN coating layers with only 500nm thickness perfectly prevented chemical reaction between cerium and steel. Vahid Firouzdor et al., [4,

5] developed Yttrium Stabilized Zirconia (YSZ) and TiO₂ coating layers on steel substrates using electrophoretic deposition. Fe/Ce diffusion couple experiments showed that TiO₂ coating reduced up to 83% solid state inter diffusion. Moreover, no diffusion was observed in 8 μ m YSZ coated Fe and Ce diffusion couple tests.

In this study, Cr coating layer was deposited on HT9 substrate using electro-deposition method. When compared to other candidate materials such as TiN, ZrN, YSZ, and TiO₂, Cr obtains higher level of comparability with cladding. For example, thermal expansion coefficients of Cr and Fe are similar. Therefore, Cr coating is expected to sustainably prevent chemical diffusion between metallic fuel and cladding. Our previous publications showed FCCI was successfully prevented by Cr coating layer. Electro-deposition is simple and efficient method for Cr coating. Hexavalent chromium (Cr⁶⁺) in an aqueous solution is deposited on substrate by applied electric current.

Because the service environment of cladding is the core of SFR, a cladding is exposed to elevated temperature ~650 $^{\circ}$ C for thousands hours. Therefore, it is essential to investigate if the microstructure and property of Cr coating layer is modified at the target temperature for prolonged time. However, to the best of the authors' knowledge, the information of Cr coating layer property at that temperature is limited. In this study, Cr coated HT9 disks were heated at 650 $^{\circ}$ C for 50 and 250 hours. The microstructure of Cr coating layers was then observed to examine the influence of thermal cycle on the property of Cr layers.

2. EXPERIMENTAL

The detailed experimental procedure was described in [2, 6, 7]. Therefore, only a brief description is provided here. Cr electro-deposition was performed on polished HT9 disks. While HT9

disk was coated by Cr at cathode, Pb-Sn alloy was selected as anode. A sargent bath is water based solution composed of 250 g/l chromic acid (CrO_3) and 2.5 g/l sulfuric acid (H_2SO_4). The temperature of sargent bath was maintained at 50 °C and 80 °C during the electro-doposition. Both temperatures were selected because the property of Cr coating layer was dramatically changed at those temperatures. While the hardness of Cr coating layer is greater and cracks are observed at 50 °C coating, 80 °C coating result in crack-free and softer Cr layer. Moreover, the thickness of Cr coating layer at 50 °C is almost twice the layer coated at 80 °C [6]. HT9 disks Cr coated at 50 and 80 °C for 70 mins were vaccum sealed in a glass to prevent oxidation at high temperature. The vaccum sealed glass was then inserted in a box furnace and heated at 650 °C for 50 and 250 hours. Specimens were cut in half after heating tests to reveal the cross section. Microstructure of polished cross sections was observed using Scanning Electron Microscopy (SEM, Model Tescan, VEGA easy probe).

3. RESULTS AND DISCUSSION

While the thickness of Cr layer at 50 °C was 40 μm, only 25 μm thickness was obtained by 80 °C coating. This thickness difference implies that Cr deposition is more efficient at 50 °C than 80 °C. Another important feature observed in the Cr layer at 50 °C is cracks. The direction of most cracks is proportional to the growth direction of Cr. Moreover, they seem to be indistinct and looked as slight defects. It is known that cracks are formed due to the volume shrinkage of chromium hydrides deposited in Cr layer. The stress increases with increasing thickness of coating layers.

The slight cracks observed in as-deposited Cr layer became more noticeable in heat treated Cr layer for 50 hours. The cracks were even more obvious in the heat treated Cr layer for 250 hours. Interfacial debonding was observed at the interface between HT9 and Cr layer. In the light of the fact that actinide and rare earth elements could easily diffuse through those deep cracks, it is beneficial to produce Cr layer without cracks. Meanwhile, unlike the deposited Cr layer at 50 °C, the 80 °C Cr layer maintained crack-free microstructure even after heat treatments.

4. CONCLUSIONS

Electro-deposition was performed to coat Cr layers on HT9 disks to hinder FCCI at both 50 °C and 80 °C. Cracks are observed only in the Cr layer coated at 50 °C due to the thickness. The observed cracks became severer after heat treatment at 650 °C for 50 and 250 hours. Meanwhile, the Cr layer coated at 80 °C maintained its crack-free microstructures even after the heat treatments. Because cracks are diffusion paths for actinides and rare earth materials, 80 °C bath temperature seems to produce better Cr coating layer to prevent FCCI.

ACKNOWLEDGEMENT

This work was conducted under the ‘SFR Cladding Development Project’ supported by the National Nuclear R&D program through the Sodium-cooled Fast Reactor Development Agency funded by the Ministry of Science, ICT and Future Planning.

REFERENCES

- [1] I. Kim, F. Khatkhatay, L. Jiao, G. Swadener, J.I. Cole, J. Gan, H. Wang, *Journal Of Nuclear Materials*, 429 (2012) 143-148.
- [2] J.H. Kim, H.J. Ryu, J.H. Baek, S.J. Oh, B.O. Lee, C.B. Lee, Y.S. Yoon, *Journal Of Nuclear Materials*, 394 (2009) 144-150.
- [3] F. Khatkhatay, J. Jian, L. Jiao, Q. Su, J. Gan, J.I. Cole, H. Wang, *Journal Of Alloys And Compounds*, 580 (2013) 442-448.
- [4] V. Firouzdar, J. Brechtel, L. Wilson, B. Semerau, K. Sridharan, T.R. Allen, *Journal Of Nuclear Materials*, 438 (2013) 268-277.
- [5] V. Firouzdar, J. Brechtel, B. Hauch, K. Sridharan, T.R. Allen, *Applied Surface Science*, 282 (2013) 798-808.
- [6] S.W. Yang, H.J. Ryu, J.H. Kim, B.O. Lee, C.B. Lee, *Journal Of Nuclear Materials*, 401 (2010) 98-103.
- [7] H.J. Ryu, B.O. Lee, S.J. Oh, J.H. Kim, C.B. Lee, *Journal Of Nuclear Materials*, 392 (2009) 206-212.