Study on the Fabrication of Magnetite-Coated Fuel Cladding Specimens for CILC Evaluation Using a Slurry Coating Method

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1. Introduction

In pressurized water reactors (PWRs), the deposition of Corrosion-Related Unidentified Deposit (CRUD), primarily composed of iron and nickel oxides, on fuel cladding surfaces significantly impacts reactor safety and operational efficiency [1-3]. In particular, CRUD deposition can lead to critical operational issues such as crud-induced localized corrosion (CILC) [4]. The evaluation of CILC is essential to ensure the safe and efficient performance of PWRs because the formation of CRUD layers on the surface of fuel cladding cannot be avoided during reactor operation. Hence, it is necessary to fabricate fuel cladding specimens with attached CRUD layers to evaluate CILC.

CRUD deposition can be experimentally simulated using a loop system under primary system conditions of PWRs [3, 5, 6]. However, this method poses challenges in controlling the morphology of the CRUD layer including porosity and thickness, and results in the formation of rough CRUD layers. The precise control of the porosity and thickness of the CRUD layer plays a key role in assessing critical factors influencing CILC [7]. To address this limitation, a slurry coating method was introduced for forming controlled CRUD layers in this study. This method offers the advantage of controlling the porosity and thickness of the CRUD layer with high precision, facilitating effective experimental assessment of CILC.

Therefore, this study explores the fabrication of magnetite-coated fuel cladding specimens using a slurry coating method. The feasibility of this approach was evaluated by analyzing the microstructure of the fabricated specimens.

2. Methods and Results

A magnetite-based slurry solution was prepared by mixing magnetite powder with a solvent binder to achieve a concentration of 30%. The prepared slurry was used for coating the surface of the fuel cladding specimens via a dipping process. The specimens were immersed in the slurry for 10 s and then withdrawn, followed by drying in air for 4 h. After drying, the coated specimens were subjected to heat treatment in a vacuum furnace to remove the binder and form a magnetite layer representative of CRUD deposits. The temperature was gradually increased to 400 °C, maintained for 40 h, and then cooled to room temperature by furnace cooling. The fabricated specimens were characterized to evaluate their suitability for CRUD simulation using X-ray diffraction (XRD) analysis and focused ion beam scanning electron microscopy (FIB-SEM).

XRD analysis was performed to analyze the crystalline structure of the magnetite coating layer after heat treatment. Fig. 1 shows the XRD pattern of the coating layer. The pattern reveals that the crystalline structure of magnetite was retained with no detectable peaks corresponding to other phases. This result indicates that the heat treatment process did not induce phase transformation.

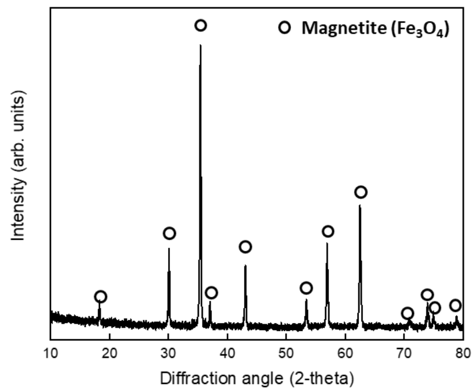

Fig. 1. XRD result of the coating layer after heat treatment.

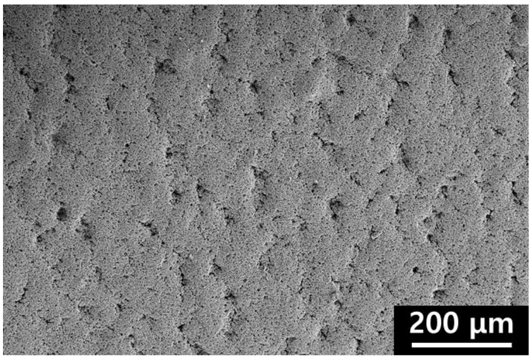

Fig. 2. SEM image of the surface of the magnetite coating layer after heat treatment.

Microstructures of the magnetite-coated fuel cladding was characterized to evaluate the similarity with CRUD formation. Fig. 2 shows the SEM image of the surface of the magnetite coating layer. The result reveals that magnetite was coated onto the fuel cladding surface in a porous form with numerous voids observed on the surface. These voids are speculated to form due to the difference in the coefficient of thermal expansion between the fuel cladding and the magnetite layer during the heat treatment process.

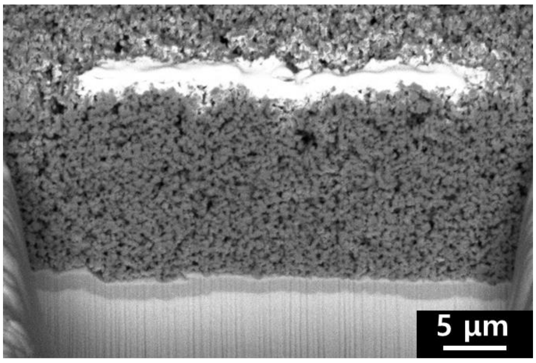

Fig. 3. Cross-sectional SEM image of the magnetite coating layer after heat treatment.

Fig. 3 shows the cross-sectional SEM image of the magnetite coating layer. The result confirms that a porous magnetite layer with a thickness of approximately 20 μm was formed. Additionally, an oxide layer was observed on the surface of the cladding, which is speculated to be zirconium oxide. These observations indicate that the slurry coating method successfully emulates key characteristics of CRUD deposits, particularly its porous structure. Based on these results, the feasibility of specimen fabrication for CILC studies was positively evaluated.

3. Conclusions

In this study, a slurry coating method was used to fabricate a magnetite-coated fuel cladding specimen with a uniform thickness and porous structure for CILC studies. The characterization results confirmed the successful formation of a porous magnetite layer similar to CRUD deposits observed in nuclear power plants. These findings confirm the feasibility of fabricating specimens emulate key characteristics of CRUD deposits, providing a promising approach for experimental CILC studies

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