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Development Status on the Barrier Technology for preventing Fuel-Cladding Chemical Interaction (FCCI)

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1. Introduction

Metallic fuel has been selected as a candidate fuel at the sodium-cooled fast reactor (SFR) because of its superior thermal conductivity as well as enhanced proliferation resistance in connection with the pyroprocessing. However, metallic fuel suffers eutectic reaction (FCCI) with the fuel by reducing cladding thickness to endanger reactor safety [1]. In order to mitigate FCCI, KAERI has initiated research since 2007 by applying barrier material between the fuel and the cladding to prevent interdiffusion process. This paper describes the brief status regarding the barrier technology in KAERI for enhancing fuel performance in SFR.

2. Parameter development

2.1. Selection of barrier material

Selection of candidate barrier material has been performed in the earlier study [2]. Zr, Nb, Ti, Mo, Ta, V and Cr metallic foil was placed between the metallic fuel and the FMS and the diffusion couple test of U-Zr-X metallic fuel and ferritic-martensitic steel (FMS) clad material was conducted at 800^{o}C for 25 hours. In the study, V and Cr revealed to be excellent FCCI resistance by suppressing both interdiffusion and eutectic reaction.

2.2. Scoping coating method

Not only selecting right barrier material, but also setting up the relevant coating method is of importance because barrier material should be uniformly coated at the inner surface of fuel cladding which has 5.8mm inner diameter and 3m in length. Zr and V layer has coated by the physical vapor deposition and their performance was evaluated using diffusion couple test, which showed reasonable result [3,4]. Cr layer was plated at the FMS cladding surface by the electroplating, where it revealed as effective except for the generation of vertical crack during the plating [5]. Protective oxide was attempted to form on the clad surface by either spontaneous oxidation [6] or the plasma electrolytic oxidation (PEO) [7].

2.3. Optimization

From the previous study, Cr electroplating has been selected as one of the probable candidate because it has cost effectiveness and well-established technology when compared to the other methods. However, it was revealed that vertical crack generated during the plating which acts as the diffusion path for the fuel component during the diffusion couple test. Research has focused to reduce such crack to enhance Cr barrier performance. In terms of this, changing bath temperature and current density were tried [5]. Pulse plating by altering current density with time and heat treatment after the plating has performed to reduce residual stress which induces internal crack [8]. After the treatment, internal stress profile inside the Cr layer was measured using nanoindentation as shown in Fig. 1. Specimen plated without any treatment showed higher internal stress whereas pulsed plating alleviated internal stress to the certain level. Heat treatment after the plating decreased the internal stress to the level of FMS clad. Diffusion couple test of the each sample showed the excellent result when compared to the conventional plating.

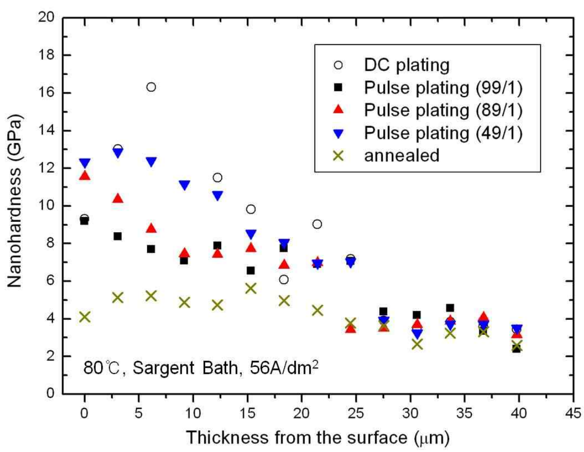

Fig. 1 Nanohardness profile of the Cr-electroplated specimen with the various plating parameter

3. Application to cladding inner surface

3.1. Barrier cladding manufacture

To demonstrate barrier technology which has developed at the planar disk specimen, application to the inner surface of the cladding has been carried out. Zr layer having 0.3 ㎛ thickness has been coated at the cladding inner surface by the metal-organic chemical vapor deposition (MOCVD) technique [9]. Regarding Cr electroplating, circulating loop to plate inner side of the cladding was constructed as published elsewhere [9]. 20 ㎛ of Cr has uniformly plated at the inner surface of the 9Cr-2W FMS tube having 4.6mm inner diameter and 170mm length. It successfully fabricated as the fuel rod and is now being irradiated at the HANARO research reactor [10].

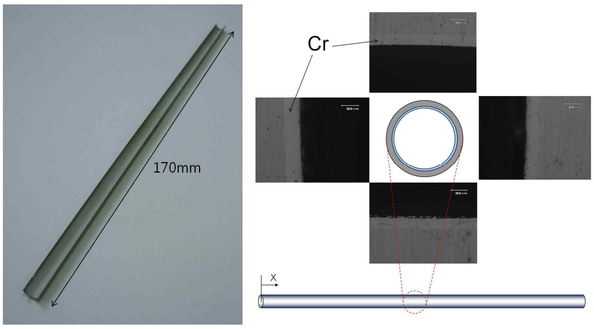

Fig. 2 Cr-plated barrier cladding prototype

3.2. Performance evaluation

Barrier should have not only chemical resistance against interdiffusion between the fuel and the cladding, but also good mechanical compatibility while confronted with the cladding matrix. To test the coherency between the barrier and the matrix, mechanical test like tensile test is now being conducted. Performance of the thermal stress difference between the barrier material and the cladding matrix is now being performed using thermal cycling test. In-reactor FCCI performance will be evaluated at the end of 2011 through the PIE of the irradiated fuel rod.

4. Summary and future perspective

This paper describes a brief summary of barrier technology by KAERI. Selecting optimal material as well as scoping relevant coating process revealed that plating either V or Cr is effective at present in terms of technical maturity and economical advantage. Prototype barrier cladding has been manufactured and is now being irradiated at the HANARO research reactor. Further research will be performed like optimizing barrier property and extending barrier coating to the longer tube (~1m). Innovative barrier technology like electrophoresis and ionic liquid technology, plasma nitrification (PIII) will be developed in the near future.

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