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Technology Development of Barrier Cladding for the Metal Fuel

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1. Introduction

Metal fuel has advantages due to their superior proliferation resistance in connection with pyroprocessing as well as excellent thermal performance. Stainless steels such as austenitic and ferritic-martensitic steel (FMS) are considered as cladding materials used for fast reactor fuels due to their higher mechanical properties than those of conventional Zr cladding under the operating condition. However, steel claddings react with Actinide elements (U, Pu, etc.) in the metal fuel near the reactor operating temperature (~650ºC) and eventually melt into thinner claddings; and hence their use is limited under severe reactor operational conditions such as high temperature and high-burnup. To suppress Fuel-Cladding Chemical Interaction (FCCI), a concept of barrier cladding by applying functional material between cladding and metal fuel has been suggested. Electroplating and metal liner fabrication have been chosen as important candidates for barrier technique based on parametric analysis regarding materials and manufacturing processes [1]. This study summarized the technical status of barrier cladding development for the usage of metal fuel and future perspective.

2. Development of Cr Electroplating Technology

2.1. Parametric study

Electroplating process contains various parameters (temperature, current density, current shape, etc.) that affect layer property [2]. It is known that Cr layer composes of nodular structure, which develops into a crack during the operating temperature so that it act as a path for fuel constituent. Suppressing crack inside the Cr plating is needed to enhance layer performance. Effect of solution temperature, current density and current shape has been carried out using disk specimen to find out optimal condition to minimizing crack. Fig. 1 shows the effect of solution temperature on the Cr layer property, where size of nodule decreases as solution temperature increases. Hardness of layer, which represents the internal stress of the layer also decreases so that tendency of crack length will decreases. Effect of current shape (pulse current) and post-treatment has been conducted to enhance the microstructure. The result showed that pulse current (on and off ratio=1:1) improves Cr layer by decreasing defect (number of pore shown in Fig. 2) inside the layer [3]. Conversion of nitride by post-treatment has been performed, which enhances the property of Cr layer.

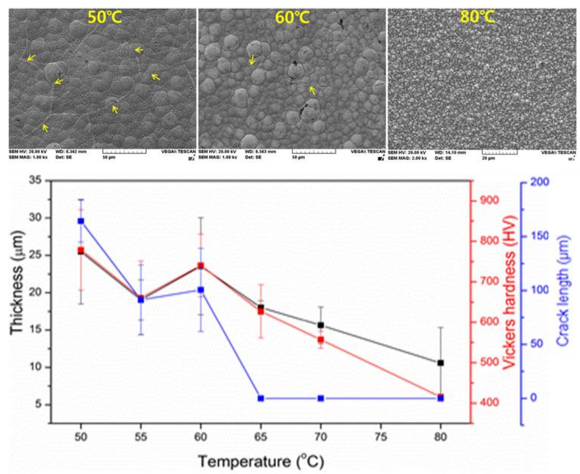

Fig. 1 Effect of solution temperature on the Cr electroplated layer

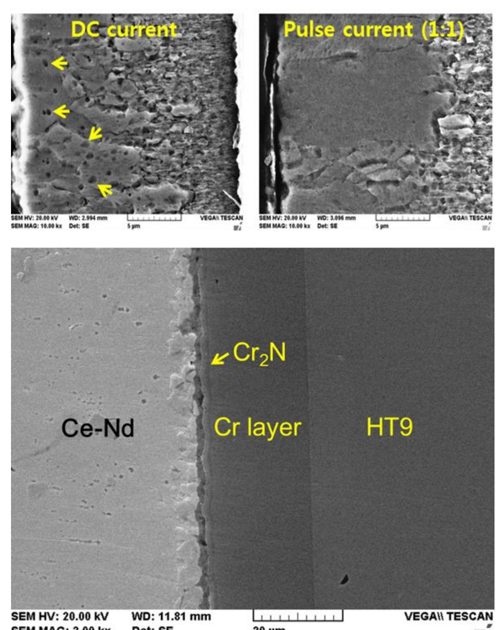

Fig. 2 Microstructure of Cr layer by pulse plating and nitriding by post-treatment

2.2. Application over tube surface

Coated tube sample has been manufactured to demonstrate the coating technology into the tube inner surface. 2mm diameter of 90Pb-10Sn wire has been inserted at the center of cladding tube as an anode, which was electrically insulated by Teflon. Electroplating was carried out by applying current at the electrolyte which flows inside the cladding tube. Sargent bath (100 : 1 ratio of CrO_3 and H_2SO_4) was prepared as an electrolyte. Periodic flow reversal and circumferential rotation was carried out to achieve homogeneous layer property. The results showed that 20μm of Cr layer has uniformly coated at the 300mm length HT9 cladding (7.4mm outer diameter and 0.5mm thickness). Further test will be done by extending longer tube at 1m scale.

2.3. Performance evaluation

Kinds of performance tests have been done at the manufactured cladding. Out-of pile FCCI test by diffusion couple test (Rare-earth, U-Zr) has been performed. In-pile FCCI test was being done at HANARO (1^{st} at 2010, 2^{nd} is in preparation) and ATR in United States, where it shows that Cr layer can hinder interdiffusion between fuel and cladding component. Mechanical tests by uniaxial tension and biaxial burst test showed that Cr layer can sustain sufficient strain (5% plastic strain) prior to rupture [4]. Long-term stability of the Cr-layer by pressurized creep test is being carried out.

3. Production of Liner Tube

Metal liner tube has been selected as one of the barrier candidates because it can assure stable barrier property once its manufacturing technology has been established. Parametric study of liner tube by material selection, the effect of cold working, heat treatment and joining interface between tubes was carried out. After elaborating process, manufacturing process has been drawn by preparing separate tube (Cold pilgering over liner tube and cold drawing over cladding tube) then joining together by cold drawing to adjust the required dimension. Based on the procedure, 50μm of Zr has been lined at the inner surface of HT9 cladding. Further studies by applying various liner materials (Ti) and extending longer length is being progressed.

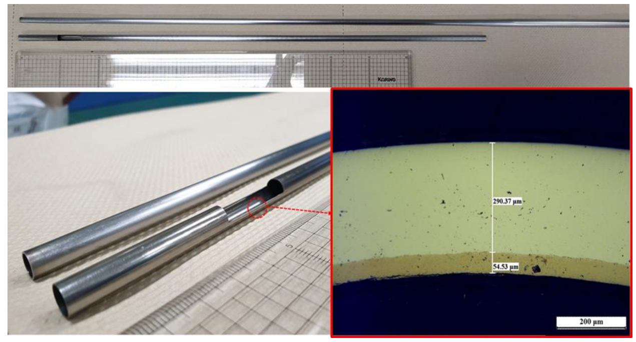

Fig. 3 Sample of HT9 cladding lined with 50μm thickness Zr (500mm in length)

4. Conclusion

Studies were conducted to develop the barrier cladding where functional material is applied at the inner side to suppress FCCI. By applying various parameters, 20μm of Cr by electroplating and 50μm of Zr by lining has been applied at the HT9 cladding. Further studies like enhancing cladding length as well as optimizing manufacturing parameters will be performed.

Acknowledgement

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