Development of Environmental Barrier Coatings for Fuel Cladding Application

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1. Introduction

After the Fukushima nuclear accident, it was demonstrated that Zr-based alloys do not maintain their integrity under uncontrollable conditions [1,2]. The reaction between zirconium and steam at high temperatures is accompanied by the release of large amounts of hydrogen gas [3,4]. In the case of Fukushima, this resulted in explosions, which severely damaged external plant buildings. There have been various attempts to reduce hydrogen related risks in nuclear reactors and the related issues have been widely discussed [5-7]. A simple solution to prevent or reduce the possibility of hydrogen explosions in severe accidents and beyond design basis accident may be to replace the current Zr-based alloy fuel cladding with silicon carbide (SiC) ceramics.

SiC-based composites are one of the candidate materials for accident-tolerant fuel (ATF) cladding because of its excellent hot steam corrosion resistance, high temperature strength, irradiation stability, and low neutron absorption cross-section [8]. However, SiC is likely to dissolve into the high temperature pressurized water [9]. There is a consensus that the SiC composites need the environmental barrier coating (EBC) for ATF applications.

In this study, Cr-added EBC coatings were deposited by hybrid PVD method and their hydrothermal corrosion behavior was investigated.

2. Methods and Results

EBC can effectively prevent corrosion of fuel cladding during normal operation. Unlike metal-based ATF cladding, the SiC composite itself has excellent accident resistance. Therefore, EBC materials for SiC fuel cladding should focus on improving corrosion resistance in normal operating environments rather than improving accident resistance. In this study, we selected ternary Cr-Al-N ceramics for EBC materials which have relatively low thermal expansion coefficient, high corrosion resistance, and good mechanical properties. The ternary Cr-Al-N coatings were deposited using hybrid PVD method. Fig. 1 shows surface images of the CrN and Cr-Al-N coatings on the on Zr disk substrates after deposition process. Fig. 2 shows the X-ray diffraction peaks of Cr-Al-N coatings as a function of Al content. Fig. 3 shows the SEM cross-sectional micrographs of CrN and Cr-Al-N coatings.

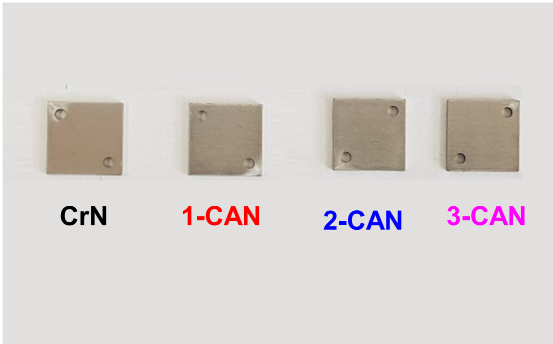

Fig. 1. Surface images of the CrN and Cr-Al-N coatings on the on Zr disk substrates; (a) CrN, (b) 1-CAN (c) 2-CAN and (d) 3-CAN.

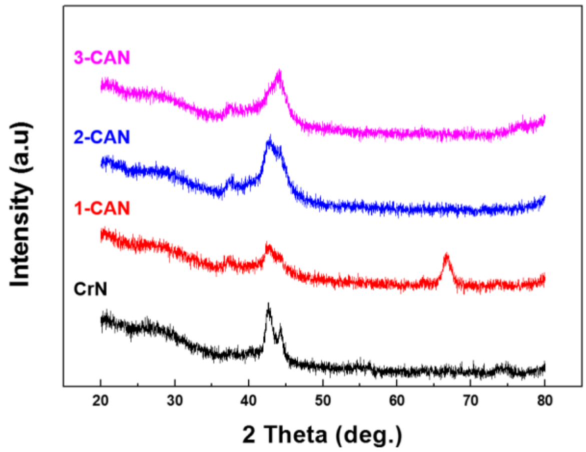

Fig. 2. X-ray diffraction peaks of Cr-Al-N coatings; (a) CrN, (b) 1-CAN (c) 2-CAN and (d) 3-CAN.

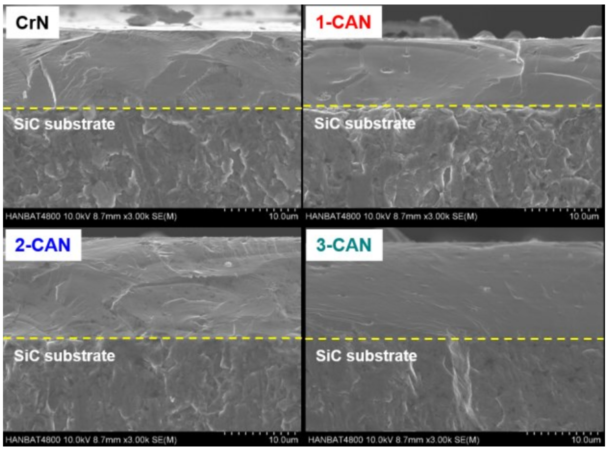

Fig. 3. SEM cross-sectional micrographs of CrN and Cr-Al-N coatings; (a) CrN, (b) 1-CAN (c) 2-CAN and (d) 3-CAN.

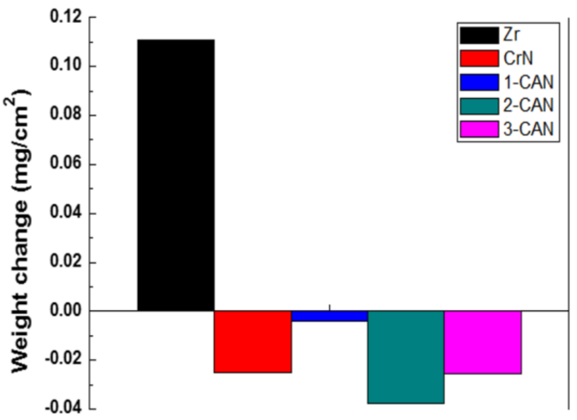

Fig. 4. Weight changes of Zr alloy and Cr-Al-N coatings.

Hydrothermal corrosion tests were carried out for 60 days in 310°C, 10 MPa water in static autoclave for the selection of coating materials. Fig. 4 shows the weight changes of Zr alloy, CrN, 1-CAN, 2-CAN and 3-CAN. Compared with a Zr alloy, weight gain of Ti and TiCr alloys is small. CAN ceramics showed weight loss due to the dissolution. In particular weight loss of 1-CAN coating was extremely small at -0.0042 mg/cm^2 after 60 days

Zr alloy and SiC-based fuel claddings are likely to be corroded in the high temperature pressurized water under neutron irradiation. Cr-based EBC can effectively prevent corrosion of Zr alloy and SiC-based fuel cladding. The CAN ceramic has excellent corrosion resistance.

The EBCs will be deposited on the commercial zirconium alloy cladding tube and silicon carbide cladding tube by hybrid PVD technique and evaluate their hydrothermal corrosion behavior in a simulated PWR water loop at 360 °C and 18.5 MPa.

Acknowledgement

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