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Metal-Ceramic Hybrid Fuel Cladding Tubes aiming at Suppressed Hydrogen Release Properties

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1. Introduction

Commercial nuclear fuel cladding tubes are currently made from various zirconium alloys. These alloys are used because they have reasonable strength at normal operating conditions and have fairly low neutron capture cross sections. However, there are several limitations to the material. State-of-the-art zirconium alloys are applicable to the high burn-up of ~70 GWD/MTU, but it is difficult to use more than that burn-up because of claddings' embrittlement. Zirconium alloys absorb hydrogen during the operation, and become brittle due to the hydride formation within the claddings. Also, zirconium alloys form an oxide layer that reduces the effective thermal conductivity of the cladding. The oxide layer also decreases the durability of the fuel cladding tubes by consuming the zirconium matrix. Since metals would be soften or melt at high temperature, the zirconium alloys are weak in the situation of accident such as LOCA and RIA. Last but not least, zirconium alloys are susceptible to fretting wear between a fuel rod and spacer grid.

Recently, ceramic claddings are being investigated in order to replace the zirconium alloys and improve the current cladding performance revolutionary (Fig. 1). In contrast to metallic fuel claddings, ceramic claddings are advantageous to the high temperature application. Especially, SiC is a main candidate material for the fuel cladding tubes used in LWRs. SiC is durable up to 1500°C without a loss of strength. Creep deformation is not observed below 34 MPa of pressure difference. SiC is resistance to the fretting wear because of its very high hardness. Moreover, there is no hydride-induced embrittlement and oxide formation. Therefore, SiC is expected to be used as up-graded cladding tubes in LWRs as well as next generation nuclear power plants.

Meanwhile, the outbreak of hydrogen explosion at Fukushima dai-ichi nuclear power plant intrigued the full-fledged R&D on ceramic claddings. Hydrogen is generated during the oxidation of zirconium alloys, and the reaction is getting more or more vigorous as the cladding temperature increases. Thus, the suppressed release of hydrogen becomes the main target of being developed LWR fuel cladding tubes. In Korea, a new R&D program to develop innovative fuel cladding tubes, which reduces the release of hydrogen during operation as well as accident, has been launched in this year. In the current paper, the metal-ceramic hybrid fuel cladding tube will be introduced among the various concepts for the suppressed hydrogen-release fuel cladding tubes.

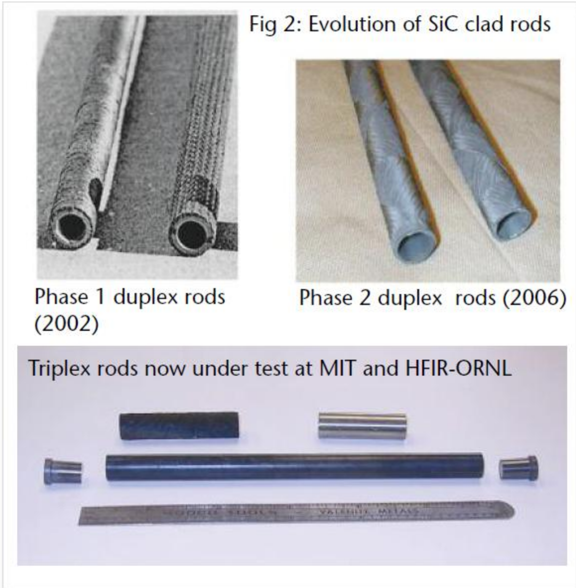

Fig. 1. Ceramic fuel claddings under development in USA (Consortium of MIT, ORNL, INL, and CTP) [1]

2. Methods and Results

2.1 Concept and Design

Fully SiC-based composite cladding has been suggested and evaluated preliminarily in US as shown in Fig. 1. The cladding is consisted of three layers of different types of SiC materials. The structure was designed to complement the brittle nature of SiC ceramics. However, several technical issues still remained in SiC triplex tubes that impede the application into industrial settings. In that sense, metal-ceramic duplex claddings were proposed [2] in order to accelerate the development of the fully SiC triplex claddings. Utilizing a zirconium inner liner in the claddings, two major concerns of (i) confinement of fission gas release and (ii) joining of end caps are definitely resolved.

The metal-ceramic hybrid cladding is consisted of inner zirconium tube and outer SiC fiber-matrix SiC ceramic composite (Fig. 2). The inner zirconium allows the matrix to remain fully sealed even if the ceramic matrix cracks through. The outer SiC composite can increase the safety margin by taking the merits of SiC itself.

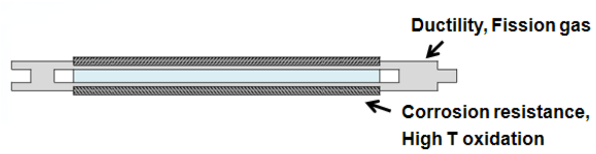

Fig. 2. Schematic illustration of metal-ceramic hybrid fuel cladding tubes

2.2 Expectations

The manufacturing process for the metal-ceramic hybrid cladding would be simplified in compared to SiC triplex claddings. First, filament winding of SiC fiber on metallic tubes needs less care in handling the substrate tubes. Second, polymer impregnation and pyrolysis can be applied since the inner liner can completely prevent the fission gas release. In addition, chemical vapor deposition of SiC for the infiltration process is quite expensive, very sensitive to process conditions, and improper to mass production. Third, end caps can be welded without difficulty as in the commercial zirconium tubes.

The expected performance of SiC would be exhibited in the metal-ceramic claddings. However, the metal to ceramic interface structure and its physical soundness during irradiation seemed to be a new concern. In addition, the outermost layer is required to be coated other than SiC materials according to our experiences. Fig. 3 shows the weight loss of SiC during a corrosion test in 360°C water. The results indicate that SiC surface coating as an outer environmental barrier should be reconsidered (also same in triplex claddings).

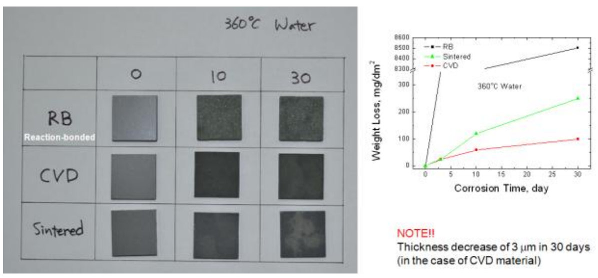

Fig. 3. Appearance of SiC and weight loss after corrosion test in 360°C water for 30 days.

3. Conclusions

For the application in LWRs with suppressed hydrogen release, the metal-ceramic hybrid cladding tube has been proposed. The cladding is consisted of inner zirconium tube and outer SiC fiber-matrix SiC ceramic composite. The cladding is advantageous to decreased hydrogen release, higher safety margin, manufacturability (e.g., filament winding, matrix infiltration, end cap joining).

Acknowledgment

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