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Manufacturing Process for the Metal-Ceramic Hybrid Fuel Cladding Tube

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1. Introduction

For application in LWRs with suppressed hydrogen release, a metal-ceramic hybrid cladding tube has been proposed [1]. The cladding consists of an inner zirconium tube and outer SiC fiber-matrix SiC ceramic composite. 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 the SiC itself. However, it is a challenging task to fabricate the metal-ceramic hybrid tube. Processes such as filament winding, matrix impregnation, and surface costing are additionally required for the existing Zr-based fuel cladding tubes. In the current paper, the development of the manufacturing process will be introduced.

2. Methods and Results

A general manufacturing process for metal-ceramic hybrid cladding is demonstrated in Fig. 1. The first stage of the fabrication is the same as a conventional manufacturing process for zirconium fuel cladding tubes. The inner tube was produced from a Zr-alloy ingot by repeating the pilgering and annealing. The second stage covers the fabrication of a SiC ceramic fiber composite. The SiC-fiber filament is wound on the Zr tube. The hetero interface between Zr metal and SiC ceramic can be adjusted with compliant media to minimize the material incoherence. The empty space within the fiber-wound perform is then filled with SiC-based preceramic polymer. Finally, the cladding tube is completed with surface coating to form an environmental barrier layer.

2.1 Tube Pilgering

The developed Zr tube of HANA [2,3] was used in this study. The tube was fabricated in accordance with commercial products. The final dimensions of the tube were 9.5 mm in outer diamenter, 0.57 mm in thickness, and 4 m in length.

2.2 Filament Winding

Commercial SiC fiber of Tyranno-S (Ube industry, Japan) was used in this study. A filament consists of 1600 fibers with a 8.5 μm diameter. The SiC-fiber filament was wound on a Zr tube with angles of ±55° without tension control. This was a preliminary condition, and will be optimized after a mechanical analysis. The band-width of one filament was 3.5–3.7 mm. The average thickness of the fiber-wound layer was about 0.81 mm after two complete spans of filament winding. The filament winding was performed in dry and wet conditions. A developing preceramic polymer was used in the wet process. Fig. 2 shows the fabricated tubes.

2.3 Impregnation of Composite

Preceramic polymer (PCP) synthesized by a domestic company was used to fill the open space within the fiber-wound layer. In the experiment, a two-dimensional fiber fabric of Tyranno-Lox M (Ube industry, twill weaved, Japan) was used for the process development.

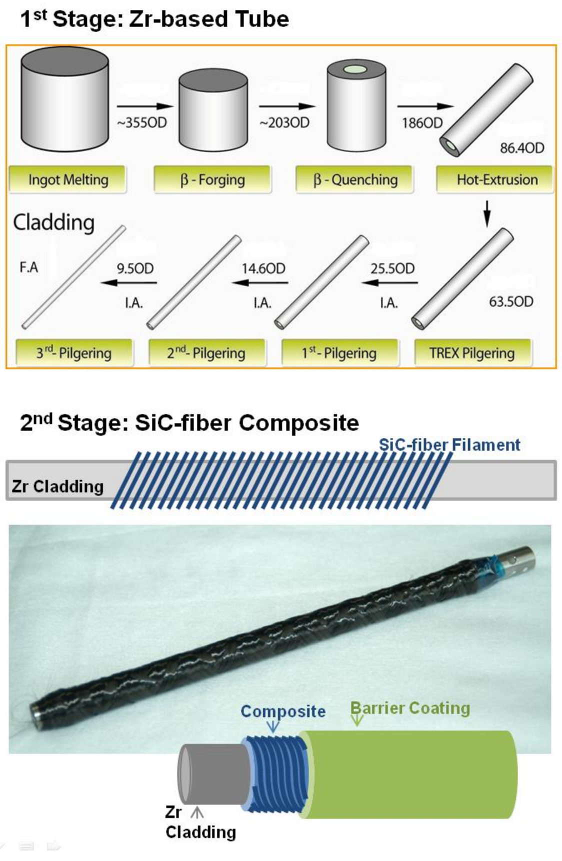

Fig. 1. Manufacturing process of the metal-ceramic hybrid fuel cladding tube. The first stage corresponds to the inner metal structure, and the second stage to the outer ceramic composite layer.

Fig. 2. Samples of metal-ceramic hybrid fuel cladding tubes after filament winding in dry (bottom) and wet (above) conditions.

SiC woven fabric was dipped in PCP-dissolved n-hexane solution. Polymer impregnation was performed under a low vacuum of 20–40 kPa. The immersed fabric was dried in air or a vacuum at 250°C, and then cured at 750°C. The effect of the PCP contents in a solvent, number of impregnation times, process atmosphere, and additional filler particles were investigated. The results will be presented in a separate paper [4].

2.4 Surface Coating

The outermost layer should be coated with corrosion-resistant materials. It was reported that SiC dissolves continuously in water at about 360°C [5,6]. The dissolution is much faster as the composition is off the stoichiometry. Since the polymer impregnation results in excess oxygen or carbon in the composite matrix, the outer environmental barrier is indispensible to prevent the expected corrosion.

Several candidates were considered as a surface coating material. Oxides such as ZrO_2, SiO_2, Cr_2O_3, and Ta_2O_5 are very stable in water. Also, the safety of fuel cladding against off-normal accidents could be increased, since the oxides can endure very high temperature. ZrO_2 in a nuclear environment has been studied a lot since it is naturally formed on conventional fuel cladding tubes [2,3]. In the case of SiO_2, the transformation of the crystal phase during irradiation was reported; however, their effect on the corrosion resistance was not investigated. Cr_2O_3 and Ta_2O_5 are quite good as a protective anti-corrosion layer, but inappropriate in terms of the neutron cross-section. A sol-gel based coating method and the synthesis of the precursor materials are being developed for the surface coating.

3. Conclusions

The manufacturing process for a metal-ceramic hybrid cladding tube was summarized. The inner Zr tube was fabricated according to the conventional pilgering and annealing processes. The inner metallic tube serves as a primary protection containment of the fission products. The outer SiC ceramic fiber composite was fabricated using filament winding, matrix impregnation, and a final surface coating. The outer ceramic composite increases the safety under high-temperature, and suppresses the release of hydrogen due to the reaction with coolant water. The development of the overall manufacturing process is on going under a national nuclear R&D project.

Acknowledgment

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REFERENCES

[1] Y.-I. Jung, B.-K. Choi, H.-G. Kim, D.-J. Park, J.-Y. Park, "Metal-ceramic hybrid fuel cladding tubes aiming at suppressed hydrogen release properties," Trans. Korean Nucl. Soc., 2012, May 17-18, Jeju, Korea.
[2] Y.H. Jeong, S.-Y. Park, M.-H. Lee, B.-K. Choi, J.-H. Baek, J.-Y. Park, J.-H. Kim, H.-G. Kim, "Out-of-pile and in-pile performance of advanced zirconium alloys (HANA) for high burn-up fuel," J. Nucl. Sci. Tech., 43 (2006) 977-983.
[3] K.W. Song, Y.H. Jeong, K.S. Kim, J.G. Bang, T.H. Chun, H.K. Kim, K.N. Song, "High burnup fuel technology in Korea," Nucl. Eng. Technol., 40 (2008) 21-36.
[4] S.-H. Kim, Y.-I. Jung, J.-Y. Park, S.-I. Hong, "Polymer impregnation and pyrolysis of Si-C-O preceramic polymer into SiC woven fabric," ibid.
[5] W.-J. Kim, H.S. Hwang, J.Y. Park, W.-S. Ryu, "Corrosion behaviors of sintered and chemically vapor deposited silicon carbide ceramics in water at 360°C," J. Mater. Sci. Lett., 22 (2003) 581-584.
[6] D.M. Carpenter, "An assessment of silicon carbide as a cladding material for light water reactors," Ph.D. Thesis, Massachusetts Institute of Technology, 2010.