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先進ブランケット用機能性被覆の実用化に向けた製作技術開発
Fabrication technology development toward practical use of functional coating for advanced blanket

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1. Introduction

Advanced fusion blankets achieve high thermal efficiency by high-temperature operation using liquid metals or molten salts as tritium breeders. In these blanket concepts, tritium permeation through structural materials, magneto-hydrodynamic pressure drop of liquid metal flow, and corrosion are critical challenges. Functional coating is one of the few promising solutions to mitigate tritium permeation, generation of eddy current in liquid metals and metal components, and corrosion simultaneously. In the last fifteen years, investigations on the functional coatings have progressed experimentally and theoretically with achievement of relevant properties [1]. Toward the application to the DEMO and commercial reactors, the functional coating study proceeds to the next phase: plant-scale fabrication and high-performance with highly-reliable coating structure.

For the plant-scale fabrication, the fabrication of homogeneous ceramic coatings on the fusion blanket components such as ducts and complex-shaped surfaces is challenging. A few coating methods have developed for the preparation on inner surfaces of duct materials; however, small plate substrates were basically used for detail analysis. Regarding the highly-reliable coating technology in a severe condition, ceramic-metal two-layer coatings have developed to protect the inner tritium permeation barrier and electrical insulating coating using a metal layer compatible with the liquid breeder [2].

In this presentation, recent progress about fabrication technology of the functional coating for plant-scale fabrication and ceramic-metal joint coating is introduced.

2. Experimental

Zirconium oxide (ZrO_2) coatings were fabricated by metal organic decomposition on both the outer and inner surfaces of 316L stainless steel tubes of half inch in diameter and up to 250 mm in length. Reduced activation ferritic/martensitic steel F82H plates were also used for the fabrication of the ceramic-metal joint coatings. The inner surface and cross-section of the tube sample were observed using a scanning electron microscope (SEM) to investigate uniformity and thickness of the coating. For the ceramic-metal joint coating, an Fe_2O_3 coating was prepared on the ZrO_2 coating as a buffer layer between ZrO_2 and metal layers. A 10 μm-thick iron (Fe) foil was joined on the ZrO_2-Fe_2O_3 coating by hot pressing for 30 min at 550 ºC and 25 MPa. Electrical resistivity measurements, liquid lithium-lead (Li-Pb) exposure tests, and gas-driven deuterium permeation measurements were performed.

3. Results and discussion

Cross-sectional SEM images indicated that the coating formed homogeneously on the inner surface of the coated tube. The coating thickness was approximately 400 nm at the heads and in the middle of the tube, as shown in Fig. 1. Electrical measurements revealed that the coating showed higher resistivities than the requirement from room temperature to 550 ºC. After the static Li-Pb exposure tests, the coating showed no delamination up to 500 h at 550 ºC, while a large-scale delamination was observed after 1000 h. The delamination would occur during the cooling procedure because the delaminated coating kept the original thickness. The thermal stress derived from a large mismatch in coefficients of thermal expansion between SS316L and ZrO_2 as well as a

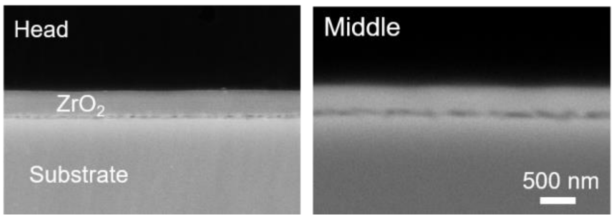

Fig. 1 Cross-sectional SEM micrographs of ZrO_2 coating prepared on the inner surface of stainless steel tube at the head and in the middle.

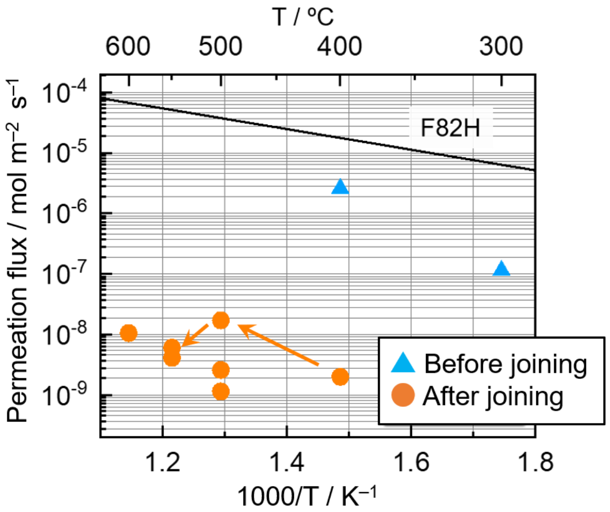

Fig. 2 Arrhenius plots of deuterium permeation flux for F82H substrate and ZrO_2-Fe_2O_3 coatings before and after joining.

decrease in adhesion of the coating by corrosion would cause the delamination.

Fig. 2 shows the results of deuterium permeation measurements for the ZrO_2-Fe_2O_3 coating before and after Fe joining. The permeation fluxes of the sample before joining decreased by an order of magnitude in comparison with that of the substrate, while that after joining decreased by a factor of approximately 7000 after the test at 500 °C. That suggests that the crystallization and/or grain growth of the ZrO_2 coating was evolved during joining without degradation of the coating. The joint coating also showed a high corrosion resistance against liquid Li-Pb under rotation flow up to 2000 h at 550 °C. Fabrication of ceramic-metal joint coating tubes using hot isostatic pressing is also ongoing.

Reference

[1] T. Chikada, Ceramic coatings for fusion reactors, in: R. Konings, R. Stoller (Eds.), Comprehensive Nuclear Materials, 2nd edition, Elsevier, Oxford, 2020, pp. 274–283.

[2] S. Horikoshi et al., Nucl. Mater. Energy 16 (2018) 66–70.