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機能性セラミックス被覆の重水素透過挙動に対する照射－腐食相乗効果

The synergy of heavy-ion irradiation and lithium-lead corrosion on deuterium permeation behavior of functional ceramic coating

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1. Introduction

Tritium permeation barrier coatings have been investigated to establish an efficient fuel cycle in fusion reactor blankets. In a liquid blanket system, irradiation damages and corrosion by liquid tritium breeders are unavoidable issues. In our previous studies, irradiation effects on lithium-lead (Li-Pb) corrosion and Li-Pb corrosion effects on deuterium permeation in zirconium oxide (ZrO_2) coating samples fabricated on reduced activated ferritic/martensitic (RAFM) steel substrates were separately investigated [1,2]. In the actual reactors, however, the coating must ensure tritium permeation barrier performance in a complex environment of irradiation and corrosion. Therefore, in this study, the deuterium permeation behavior of the ZrO_2 coating under Li-Pb exposure condition after introducing irradiation damage has been investigated to elucidate the synergy of irradiation and corrosion on hydrogen isotope permeation.

2. Experimental

RAFM steel F82H (Fe-8Cr-2W, F82H-BA07 heat) plate was used as substrate. We prepared chromium oxide (Cr_2O_3) by heat treatment under argon and hydrogen gas flow, followed by fabrication of ZrO_2 coating by metal organic decomposition. The coated sample was irradiated using Ni^{2+} with an energy of 6.0 MeV and a displacement damage of 4.0 displacement per atom (dpa) at room temperature. The damage density in the coating was calculated by SRIM-2013. Thereafter, deuterium permeation measurements under liquid Li-Pb exposure condition were conducted using the gas-driven permeation method. The Li-Pb was synthesized at the atomic ratio of Li : Pb = 15.7 : 84.3 and poured in the coated side up to approximately 1.0 cm in height. The inlet pressure and test temperature were 10–80 kPa and 300–600 ºC, respectively.

3. Results and discussion

Fig. 1 shows the temperature dependence of deuterium permeation flux for the coated sample under Li-Pb exposure. The permeation flux decreased by a factor of 13000 compared to that of the F82H substrate in the tests at 450 ºC and increased with temperature at 450−550 ºC. Besides, the slope calculated from the fitted line was steeper than that of the unirradiated-ZrO_2-coated sample, which means the activation energy of permeation was higher. After the test at 550 ºC, the activation energy of permeation at 400−600 ºC decreased and became comparable with the values of the unirradiated ZrO_2 coating. From these results, irradiation defects might increase the energy barrier of diffusion in the coating and recover at high temperatures. In addition, a corrosion product layer formed on the coating and would decelerate the solution into the coating, resulting in the significantly high activation energy of permeation at 450−550 ºC due to the combined effect of irradiation and corrosion.

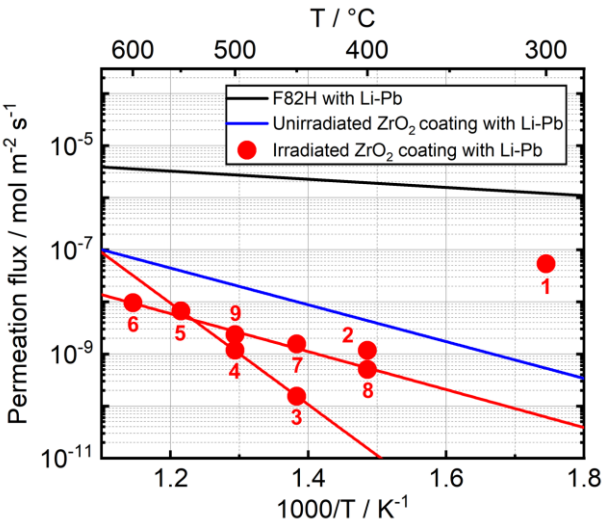

Fig. 1 Arrhenius plots of deuterium permeation flux with Li-Pb for F82H substrate and ZrO_2-coated sample with and without irradiation. Numbers next to symbols represent test sequence.

Reference

[1] S. Miura et al., Fusion Eng. Des. 170 (2021) 112536
[2] E. Akahoshi et al., Corros. Sci. 189 (2021) 109583.