Performance of the Barrier between the Metallic Fuel and the Clad Material in Sodium-cooled Fast Reactor

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1. Introduction

Metallic fuel has been considered as one of the most probable candidates of the fuel system in the Sodium-cooled Fast Reactor (SFR) in that it has high thermal conductivity, proliferation resistance, and good compatibility between sodium [1]. Addition of the alloying element such as chromium, molybdenum, zirconium and titanium was applied in order to increase the solidus temperature of the uranium-plutonium alloy. Among these, uranium-plutonium alloys with the addition of 10~20% zirconium have been considered in the design of the metallic fuel in SFR. However, actinide elements in metallic fuel like uranium and plutonium react with stainless steel at a temperature above 650^{o}C to form eutectic compounds [2]. Such eutectic reaction reduces cladding thickness so that mechanical integrity of the cladding gradually decreases as the fuel burnup proceeds. To mitigate such a circumstance, barrier layer, which prevents both fuel and clad elements from diffusing each other, has been developed. Metallic foil made of pure metal has been suggested as a barrier and its feasibility test has been carried out [3,4]. The objectives in this study are to propose several kinds of the barrier material and to verify its performance under a fuel-clad interaction situation.

2. Experimental Procedure

2.1. Specimen preparation

Both uranium-zirconium alloy (U-10Zr) and HT9 (Fe-12Cr-1.0Mo-0.6Ni-0.6Mn-0.52W-0.3V-etc.) were used as a metallic fuel and a clad in this study. They were prepared as a 6.6mm disk in fuel and an 8mm disk in clad respectively prior to the test. Barrier layers in this study were as following categories; (a) Alloy foils made from refractory elements, (b) Surface oxidation, (c) Non-metallic layer, and (d) Commercial demolding agent. In the alloy metallic foil, Nb-20Zr and V-4Cr-4Zr alloys were made and thinned down to 30 ㎛. Regarding surface oxidation, HT9 disk was oxidized in the muffle furnace at a temperature of 750^{o}C for 60 days. Oxide layer, however, was not fully developed so that its thickness was below 1 ㎛ level. Disk made of silicon-carbide fiber (SiC_f) was used as non-metallic layer. In addition, commercial demolding agent was used to investigate the possibility as a barrier. Molybden compound and boron-nitride (B-N) were chosen and they were sprayed 2~3 times onto the each cleaned HT surface before the diffusion test. Specimen without any barrier treatment was used as a reference condition.

2.2. Diffusion test

To assess the performance of the barrier, diffusion tests between the metallic fuel and the clad material were carried out. Metallic fuel disk and the barrier-treated clad disk were contacted each other. Then the coupled specimen was inserted in the screw-type jig made of 316-type stainless steel then it was clamped. Coupled specimen was wrapped with a tantalum foil to avoid unnecessary reaction between the specimen and the jig. After clamping, they were placed at the vacuum furnace then the diffusion tests were carried out. Test ran at the temperature of 800^{o}C for 25 hour. After testing, the specimens were pulled out of the furnace and quenched in the water to prevent any microstructural changes as well as an oxidation during slow cooling of the specimen in the air environment. Fig. 1 shows the schematic illustration of the diffusion test. After the test, the specimens were sectioned and the SEM/EDX analysis was carried out.

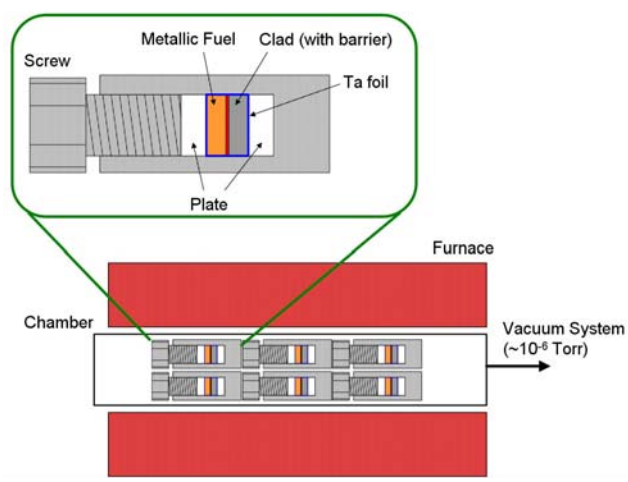

Fig. 1 Schematic illustration of diffusion test

3. Results and Discussion

3.1. Specimen without barrier treatment

Fig. 2(a) shows the fuel-clad coupled specimen without any barrier treatment exposed 800°C for 25 hour, in which considerable amount of reaction was occurred. SEM morphology revealed that the clad lost its thickness at the value of 250 ㎛. From the EDX analysis, uranium, iron and chromium diffused each other at the opposite direction.

3.2. Evaluation of the barrier performance

Fig. 2(b)~(f) shows the fuel-clad coupled specimen with the barrier treatment exposed 800°C for 25 hour. Alloy foils showed a good resistance against fuel-clad interaction. In Nb-20Zr foil, there appeared some reaction between the metallic fuel and the alloy barrier (Refer to the red arrow in Fig. 2(b)). In V-4Cr-4Zr foil, no diffusion or reaction occurred along the barrier thickness. In the oxidized specimen, however, there occurred a massive reaction between the fuel and the clad, which seemed to be similar to the specimen without barrier. It implies that the prior-developed oxide was too thin to protect the reaction between the fuel and the clad. Further research regarding the efficiency of the oxide growth is needed.

In the case of specimen layered with silicon-carbide fiber, no reaction between the fuel and the clad occurred, except for the segregation of the zirconium component around the fuel / SiC_f interface (Refer to the red arrow in Fig. 2(e)). In the commercial demolding agent, excellent property in hindering fuel-clad interaction was occurred. No inter-diffusion, not to mention of the eutectic reaction was occurred at both molybden compound and B-N sprayed specimen

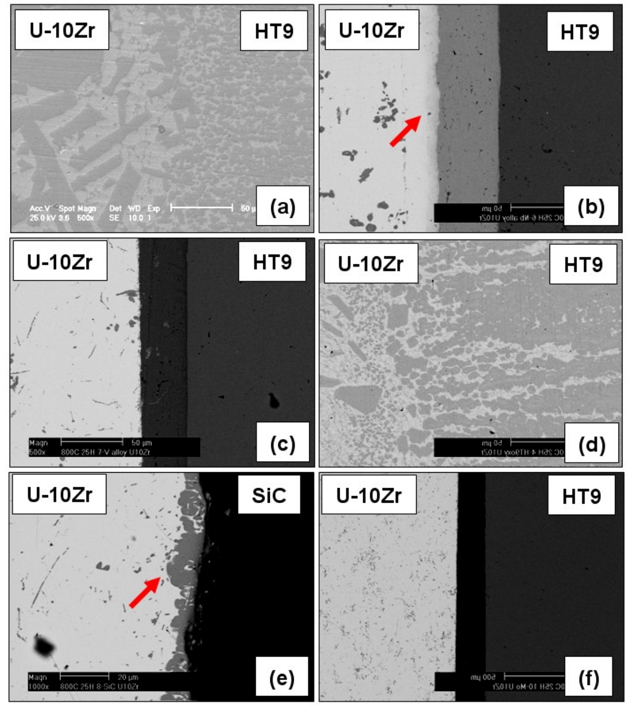

Fig. 2 Cross-sectional image of U-10Zr metallic fuel and HT9 cladding material with various barrier material after diffusion test at 800°C for 25hr. (a) without barrier, (b) Nb-10Zr alloy foil, (c) V-4Cr-4Zr alloy foil, (d) Oxidation at 750°C for 60days, (e) Silicon carbide fiber, (f) Demolding agent (molybden compound). Note that (a) ~ (d) are taken at a magnitude of 500 times, (e) of 1000 times, (f) of 60 times.

4. Conclusions

This paper summarizes the result of the screening test of the various barrier materials between the metallic fuel and the clad materials. Alloy foils, surface oxidation, non-metallic layer, and the commercial demolding agent were proposed and the diffusion test was carried out. The result showed that alloy foil like V-4Cr-4Zr, silicon carbide fiber, and commercial demolding agent exhibited an excellent property against the fuel-clad interaction. Although the oxide layer showed an unsatisfied result, it is due to the thin oxide thickness. Further studies related to the enhancement of the oxide growth are needed.

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