Interfacial reaction between dispersion type (U-10wt%Zr)-Zr fuel and HT9

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1. Introduction

The blanket fuel assembly for HYPER(Hybrid Powder Extraction Reactor) contains a bundle of pins arrayed in a triangular pitch which has a hexagonal bundle structure. Dispersion type (TRU-10wt.%Zr)-Zr fuel is considered as a blanket fuel for HYPER(Hybrid Powder Extraction Reactor). In case of dispersion type fuel, the particles of TRU-10wt.%Zr alloy are dispersed in Zr matrix. Blanket rod is made of sealed tubing containing fertile material HT9 in columns.

Uranium-plutonium-zirconium alloys have been considered one of the advanced fast reactor fuels. During irradiation, these alloys swell and come into contact with the cladding, then metallurgical reaction at the fuel-cladding interface occurs and affects the integrity of the cladding. The reaction between the fuel and the Fe-base cladding materials should be well understood in order to evacuate the fuel performance.

Several studies were conducted on the reactions between U-Zr or U-Pu-Zr alloys and stainless steels. We fabricated (U-10wt%Zr)-xZr fuel(x=50,55,60wt%) instead of the actual (TRU-10wt%Zr)-Zr fuel for HYPER. This study investigates the solid-states reaction layers formed at 700^{o}C at two kinds of diffusion interfaces: dispersion type (U-10wt%Zr)-Zr fuel/HT9 on variation with fuel composition.

2. Methods and Results

2.1 Experimental Methods

The dispersion type fuels used in this study were prepared from the U-10wt%Zr and Zr powders by extrusion process. The dispersion type (U-10wt%Zr)-Zr fuels were fabricated by mixing, pressing and extrusion. The cladding steel in this investigation is stainless steel HT9.

Both fuels and cladding steel were cut into disks about 0.5 thick. Each of the diffusion couple assemblies was encapsulate in a quartz tube. The diffusion couples were annealed isothermally at 700^{o}C. The dispersion type (U-10wt%Zr)-xZr fuel(x=50,55,60wt%)/HT9 diffusion couples were annealed at 700^{o}C for 100 h. After completion of the diffusion anneal, the couples were quenched in air, then sectioned parallel to the diffusion direction. The sectioned couple was embedded in epoxy resin and then the cross-sectional surface was polished with 1μm diamond paste for SEM. The reaction layer thickness and concentration distributions of diffusion reaction layer were measured by SEM equipped with EDAX.

2.2 Interfacial Reaction between dispersion type (U-10wt%Zr)-Zr fuel and HT9

Figure 1 shows scanning electron micrographs of the (U-10wt%Zr)-50wt%Zr fuel extruded at 850^{o}C, with an extrusion ratio of 16:1. During the extrusion, U-10wt%Zr powders are dispersed in Zr matrix by mechanical work, and they are broken and torn into harder Zr matrix along the extrusion direction. Figure shows that dispersion-type fuel consists of Zr matrix in black regions and α -U phases and δ -UZr_2 in white regions.

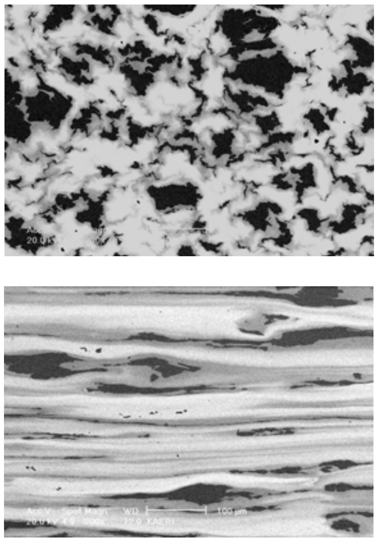


Figure 1. Photograph of dispersion type (U-10wt%Zr)-50wt%Zr fuel. (a) transverse section, (b) longitudinal section

Figure 2 shows the back-scattered electron image of the dispersion type (U-10wt%Zr)-xZr(x=50,55,60wt%) fuel/HT9 annealed at 700^{o}C for 100 h. The microstructure of dispersion type fuel after heat treatment at 700^{o}C for 100 hrs consists of α-uranium, δ-UZr_2 and α-Zirconium as shown in Figure 2. Compared with the elongated microstructure of as received sample, the grains of each phase were spheroidized. It should be noted that the content of α-uranium decreased and δ-UZr_2 increased as zirconium content in (U-10wt%Zr)-Zr fuels increased.

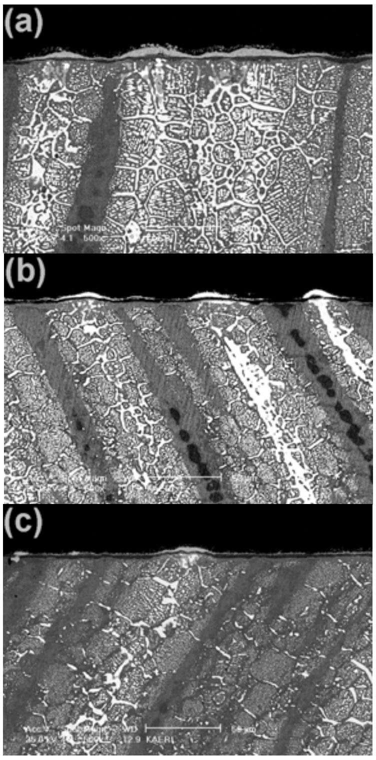


Figure 2. Photograph of the back-scattered electron image of the dispersion type (U-10wt%Zr)-50wt%Zr fuel/HT9.

The U in the fuel diffuses into HT9 cladding material with 3~5µm reaction layer. The elemental Fe in cladding material diffuses into the fuel core and then forms reaction layer of about 40µm, 15µm and 10µm in (U-10wt%Zr)-xZr(x=50,55,60wt%) fuel/HT9 couples, respectively. This is because uranium forms eutectic with iron at 740^{o}C while zirconium doesn't. So, the thickness of reaction layer between the fuel and HT9 cladding material decreased as uranium content decreased as shown in figure 2.

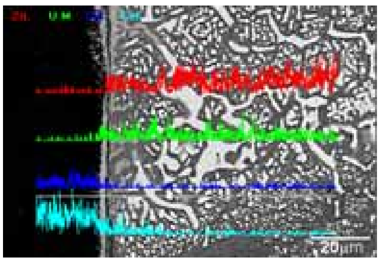
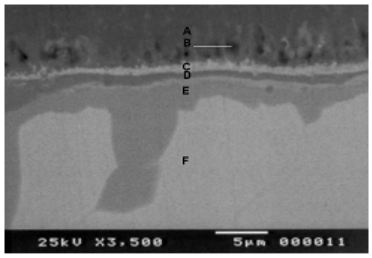


Figure 3. EDS line profiles of (U-10wt%Zr)-55wt%Zr fuel/HT9.

Figure 3 shows EDS line profiles of (U-10wt%Zr)-55wt%Zr fuel/HT9. The U in the fuel diffuses into HT9 cladding material with 5µm reaction layer. The elemental Fe in cladding material diffuses into the fuel core and then forms reaction layer of about 15µm.

Figure 4 shows the quantitative EDAX results of the dispersion type (U-10wt%Zr)-50wt%Zr fuel/HT9 annealed at 700^{o}C for 100h. Each reaction zone can be divided into several layers, layer A, B, C, D, E and F. The EDAX results are as followings: layer A, B, C, D, E and F are the cladding material, $U_2Fe_{73}Cr_{25}$, $U_{30}Zr_3Fe_{52}Cr_{15}$, $U_3Zr_{52}Fe_{38}Cr_6$, $U_{10}Zr_{66}Fe_{23}Cr_1$ and $U_{29}Zr_{70}Fe_1$, respectively.



Layer	Thickness(µm)	Comp.(at.%)
A		Cladding
B		$U_2Fe_{73}Cr_{25}$
C	~ 1	$U_{30}Zr_3Fe_{52}Cr_{15}$
D	~ 1	$U_3Zr_{52}Fe_{38}Cr_6$
E	~ 40	$U_{10}Zr_{66}Fe_{23}Cr_1$
F		$U_{29}Zr_{70}Fe_1$

Figure 4. The EDAX results of the dispersion type (U-10wt%Zr)-50wt%Zr fuel/HT9 annealed at 700^{o}C for 100 h.

3. Conclusion

The U in the fuel diffuses into HT9 cladding material with 3~5µm reaction layer. The elemental Fe in cladding material diffuses into the fuel core and then forms reaction layer of about 40µm, 15µm and 10µm in (U-10wt%Zr)-xZr(x=50,55,60wt%) fuel/HT9 couples, respectively. This is because uranium forms eutectic with iron at 740^{o}C while zirconium doesn't. The thickness of reaction layer between the fuel and HT9 cladding material decreased as uranium content decreased.

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