Interfacial reaction between U-Zr alloys and HT9

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1. Introduction

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 alloy 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. This study investigates the solid-states reaction layers formed at 700°C at two kinds of diffusion interfaces: dispersion type (U-10wt%Zr)-50wt%Zr alloy/HT9 and alloy type U-55wt%Zr alloy/HT9.

2. Methods and Results

2.1 Experimental Methods

The dispersion type fuel and the alloy type fuel used in this study were prepared from the U, U-10wt%Zr and Zr powders by extrusion process. The dispersion type (U-10wt%Zr)-50wt%Zr fuel was fabricated by mixing, pressing and extrusion. The alloy type U-50wt%Zr fuel was fabricated by mixing, pressing, sintering 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°C. The dispersion type (U-10wt%Zr)-50wt%Zr fuel/HT9 diffusion couple was annealed at 700°C for 100 h. The alloy type U-50wt%Zr fuels/HT9 couples were annealed at 700 and 750°C for 100 h, respectively. After completion of the diffusion anneal, the couples were quenched in water, then sectioned parallel to the diffusion direction. The sectioned couple was enbeded in epoxy resin and then the cross-sectional surface was polished with 3μm diamond paste for SEM. The reaction layer thickness and concentration distributions of diffusion reaction layer were measured by SEM equipped with EDAX.

2.2 Dispersion (U-10wt%Zr)-50wt%Zr fuel/HT9 couple

Figure 1 shows scanning electron micrographs of the (U-10wt%Zr)-50wt%Zr fuel extruded at 850°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. Figure shows that dispersion-type fuel consists of Zr matrix in black regions and α-U phases and δ-UZr_2 in white regions.

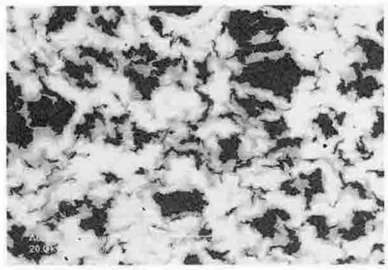


Figure 1. Photograph of dispersion type (U-10wt%Zr)-50wt%Zr fuel

Figure 2 shows the back-scattered electron image of the dispersion type (U-10wt%Zr)-50wt%Zr fuel/HT9 annealed at 700°C for 100 h. The U in the fuel diffuses into HT9 cladding material with 2~3μm reaction layer. The elemental Fe in cladding material diffuses into the fuel core and then forms reaction layer of about 50μm.

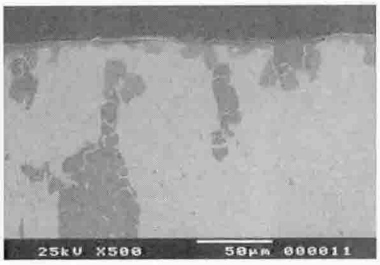


Figure 2. Photograph of the back-scattered electron image of the dispersion type (U-10wt%Zr)-50wt%Zr fuel/HT9.

Figure 3 shows the quantitative EDAX results of the dispersion type (U-10wt%Zr)-50wt%Zr fuel/HT9 annealed at 700°C for 100 h. 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)	Composition(at.%)
A		HT9
B		$U_2Fe_{73}Cr_{25}$
C	~ 1	$U_{30}Zr_3Fe_{52}Cr_{15}$
D	~ 1	$U_3Zr_{52}Fe_{39}Cr_6$
E	~ 50	$U_{10}Zr_{66}Fe_{23}Cr_1$
F		$U_{29}Zr_{70}Fe_1$

Figure 3. The EDAX results of the dispersion type (U-10wt%Zr)-50wt%Zr fuel/HT9 annealed at 700°C for 100 h.

2.3 Alloy type U-55wt%Zr fuel/HT9 couples

Alloy type U-55wt%Zr fuel was extruded at 750°C into round bars with a diameter of 8mm and an extrusion ratio of 16:1. Figure 4 shows that alloy type U-55wt%Zr fuel consists of δ-UZr_2 matrix and α-Zr phase, and that there are few pores in extrudates owing to elimination during extrusion.

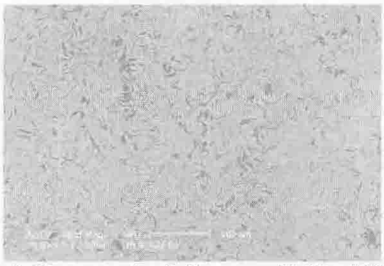


Figure 4. Photograph of alloy type U-55wt%Zr fuel.

Figure 5 shows the back-scattered electron image of the alloy type U-55wt%Zr fuel/HT9 annealed at 700°C for 100 h. The U in the fuel diffuses into HT9 cladding material with 2~3μm reaction layer. The elemental Fe in cladding material diffuses into the fuel core and then forms reaction layer of about ~40μm.

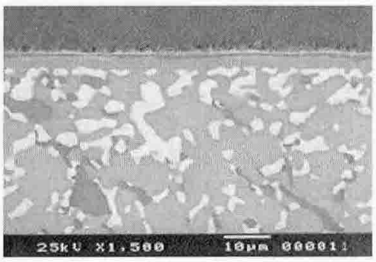
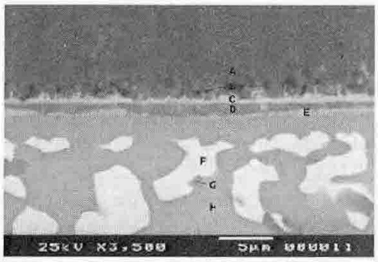


Figure 5. Photograph of the back-scattered electron image of the alloy type U-55wt%Zr fuel/HT9.

Figure 6 shows the EDAX results of the dispersion type U-55wt%Zr fuel/HT9 annealed at 700°C for 100 h. Each reaction zone can be divided into several layers. The EDAX results are as followings: layer A, B, C, D, E, F and G are the cladding material, $U_3Fe_{66}Cr_{31}$, $U_{22}Fe_{55}Cr_{23}$, $U_{11}Zr_{35}Fe_{48}Cr_6$, $U_{15}Zr_{44}Fe_{36}Cr_4$, $U_{71}Zr_{29}$, U_1Zr_{99}, and fuel, respectively. Inside fuel, □-UZr_2 matrix is decomposed and the decomposed Zr formed the Zr rich phase(layer G).



Layer	Thickness(μm)	Composition(at.%)
A		HT9
B	2 ~ 3	$U_3Fe_{66}Cr_{31}$
C	~ 0.5	$U_{22}Fe_{55}Cr_{23}$
D	~ 1.5	$U_{11}Zr_{35}Fe_{48}Cr_6$
E	~ 0.5	$U_{15}Zr_{44}Fe_{36}Cr_4$
F		$U_{71}Zr_{29}$
G		U_1Zr_{99}
H		$U_{15.5}Zr_{83.5}Fe_{0.5}Cr_{0.5}$

Figure 6. The EDAX results of the U-55wt%Zr alloy fuel/HT9.

3. Conclusion

In the dispersion fuel/HT9 couple, the U in the fuel diffuses into HT9 cladding material with 2~3μm reaction layer. The elemental Fe in cladding material diffuses into the fuel core and then forms reaction layer of about 50μm. In the alloy fuel/HT9 couple, the U in the fuel diffuses into HT9 cladding material with 2~3μm reaction layer. The elemental Fe in cladding material diffuses into the fuel core and then forms reaction layer of about ~40μm. Therefore, the alloy type fuel/HT9 had smaller diffusion zone than the dispersion fuel/HT9 couple.

REFERENCES

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