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Fuel cladding chemical interaction of U-Zr-Ce with HT9 at 800°C

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1. Introduction

U-Zr based fuels and ferritic-martensitic stainless (FMS) steel claddings have been considered as the most probable fuel for the initial core of the sodium cooled fast reactor (SFR). In this study, fuel cladding chemical interaction (FCCI) of U-10wt%Zr-5wt%Ce (U-10Zr-5Ce) fuel slugs with HT9 cladding were performed at high-temperature. After the test, the microstructures of fuel and cladding were observed through scanning electron microscope (SEM), and element distribution was analyzed using electron probe micro analyzer (EPMA).

2. Experimental Methods

2.1 Materials

U-10Zr-5Ce fuel and HT9 cladding material were used for the FCCI tests. U-10Zr-5Ce was fabricated by a modified injection casting method [1]. The cladding material used in the experiments was HT9, which includes 12 wt% Cr, 1 wt% Mo. HT9 was fabricated using vacuum induction melting and hot rolling [2]. The HT9 was normalized at high temperature of 1050 °C for 1 h and final tempering was conducted at 780 °C for 2 h. After the heat treatment, HT9 was machined into disk specimens of 6 mm diameter and 1 mm thickness for the diffusion couple test.

2.2 Experiments

The surface of the disk type of U-10Zr-5Ce and HT9 material were polished and assembled in a special holder for FCCI. The holder was made of HT9. Figure 1 shows the schematic diagram of the holder for FCCI tests. As shown in the figure, the top and the bottom plates of the U-10Zr-5Ce specimens come into contacts with HT9 plates, which enable to induce eutectic reaction of fuel with HT9 at the both sides. The surface of U-10Zr-5Ce and HT9 was finally polished with 3 μm of diamond suspension on rotating cloths followed by grinding with silicon carbide paper up to grip P2000. The final polishing and assembling were conducted in inert He environment glove box to minimize oxidation during specimen preparation.

To evaluate the fuel cladding chemical interaction (FCCI) under the transient condition of SFR, the U-10Zr-5Ce fuel with HT9 were annealed at 800 °C for 1 hour in vacuum environment of 10^{-5} torr. After the 1 hour annealing, the holder was quenched in water. The microstructures of the fuel slug and cladding were observed using scanning electron microscope (SEM, JSM-6610LV JEOL) and elemental distributions and chemical compositions in reaction layer were analyzed by both the energy-dispersive X-ray spectroscopy (EDS, Oxford Instruments) in SEM and wavelength dispersive X-ray spectroscopy (WDS) in electron probe micro analyzer (EMPA, JXA-8320 JEOL).

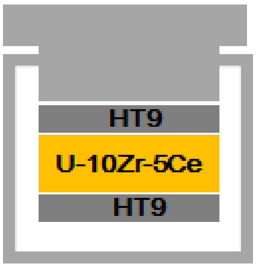

Fig. 1. Schematic diagram of the holder

3. Results and discussions

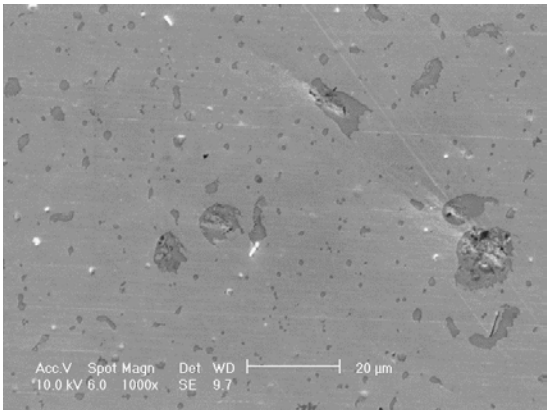

Fig. 2. SEM image of as-injection casted U-10Zr-5Ce

Fig. 2 shows the typical SEM images of as casted U-10Zr-5Ce. The major composition of grey precipitate in Fig. 2 is Ce. The average composition of the matrix is 91.6wt%U-8.4wt%Zr.

Fig. 3 shows the back scattered electron image of interaction layers between U-10Zr-5Ce and HT9 after 800 °C test. As shown in the figure, U-Zr matrix with Ce rich precipitates are observed in the fuel side, while distinct three reaction regions were developed, so-called Region- I,-II, and -III at the fuel and cladding interface.

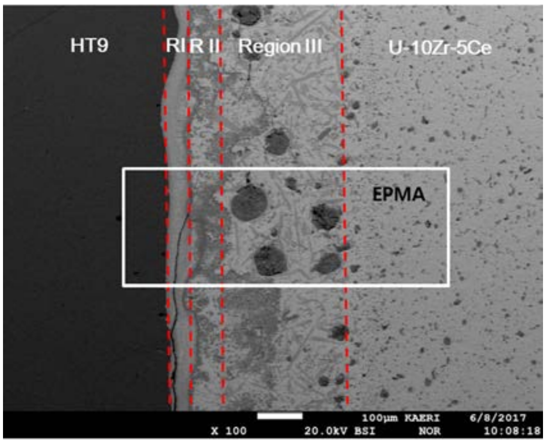

Fig. 3. Cross sectional SEM image at the interface between U-10Zr-5Ce and HT9

In the light of FCCI reaction of U-10Zr with HT9, undulating morphology in Region-I and -II seems to be eutectic reaction while dark grey circular shape inclusions with lath type precipitates in Region-III is questionable. In order to analyze the elements distribution and chemical composition of the reaction zones, EPMA mapping analysis was conducted in selected area in Fig. 3.

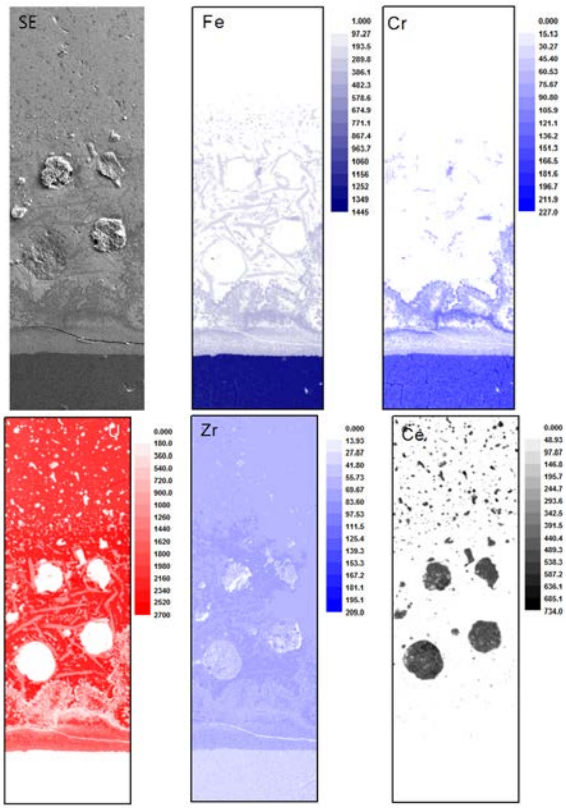

Fig. 4. Elements distribution at the reaction area

Fig. 4 shows the overall elemental distribution of EPMA results. As shown in the figure, major cladding elements, Fe and Cr are predominantly distributed in Region-I and Region-II while Fe is distributed in lath type precipitation in Region-III. On the other hand, U and Zr is observed in overall original fuel side region excluding circular areas in Region-III. The circular area was identified as Ce rich inclusions. Interestingly, concentration of U in Region-III is higher than that of the original U-10Zr-5Ce matrix.

4. Conclusions

To characterize the FCCI reaction of U-Zr based fuel under transient condition, diffusion couple test of U-10Zr-5Ce and HT9 was conducted at 800 °C. Three distinct reaction layers were observed at the interface between fuel and cladding. The major cladding elements, Fe and Cr, are distributed in Region-I and Region-II where the eutectic melting occurs. Interestingly, a significant Ce agglomeration was observed in Region-III, while Ce distribution in original fuel region was unchanged.

REFERENCES

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[2] J.H. Kim, J.S. Cheon, B.O. Lee, J.H. Kim, Journal of Nuclear Materials 479 (2016) 394-401.