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Results of High-Temperature Heating Test for Irradiated Metallic Fuel

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1. Introduction

Sodium-cooled Fast Reactor (SFR) has an advantage of enhanced reactor safety, fuel cycle economy, and environmental protection. These advantages are, to a large extent, the direct results of using a metallic fuel (U-Zr or U-Pu-Zr) as the fuel material [1]. The U and Pu constituents in the fuel, however, tend to interact metallurgically with iron-based claddings at elevated temperatures during nominal steady-state operating conditions and off-normal reactor events. In particular, if the temperature is raised above the eutectic temperature of metallic fuel, e.g., in an off-normal reactor event, the fuel can form a mixture of liquid and solid phases that may promote further cladding interaction [2,3]. Such fuel-cladding chemical interaction, in conjunction with fission gas pressure loading, can potentially shorten fuel pin lifetime and eventually cause cladding breach.

In this work, microstructure observation results through microscope, SEM and EPMA are reported for the irradiated U-10Zr and U-10Zr-5Ce fuel slugs with T92 cladding after high-temperature heating test. Also, the measured eutectic penetration rate is compared with the prediction value by the existing eutectic penetration correlation being used for design and modelling purposes.

2. Test Conditions

Short segments (length: 10 mm) cut from irradiated fuel rods which consist of U-10Zr and U-10Zr-5Ce fuel slugs with T92 cladding (thickness: 0.45 mm) [4] were heated in the furnace which was located inside hot cell facility in KAERI. The peak burnup of irradiated fuel rods was 2.87 at.% [4]. The heating temperature and duration time for U-10Zr/T92 specimen were 750 °C and 1 hr, and those for U-10Zr-5Ce/T92 specimen were 800 °C and 1 hr, respectively. The heating rate from room temperature to target heating temperature was 0.2 °C/sec. In order to prevent oxidation of test specimens during heating test, inert helium gas was applied to flow through interior of furnace at the flow velocity of 150 ml/min. Also, zircaloy-4 sheets which act as O_2 getter materials were inserted in the furnace together with test specimens. Microstructures of test specimens were observed by using the microscope, SEM and EPMA after completing the heating test.

3. Results and Discussions

Fig. 1 and 2 show a microscope photograph of U-10Zr/T92 and U-10Zr-5Ce/T92 specimen after heating test, respectively. As shown in Fig. 1, eutectic melting region was locally observed in the cased of U-10Zr/T92 specimen. However, in the case of U-10Zr-5Ce/T92 specimen, eutectic melting region was not found, because there was a gap between fuel slug and cladding which originally existed after irradiation test, and the contact between fuel slug and cladding didn't take place during heating test.

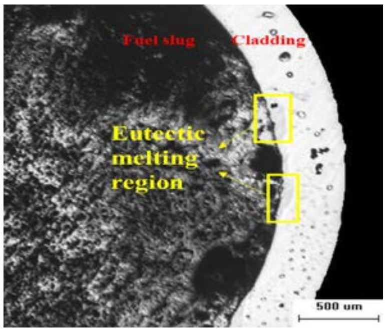

Fig. 1. Microscope photograph of U-10Zr/T92 specimen after heating test (750 °C, 1 hr).

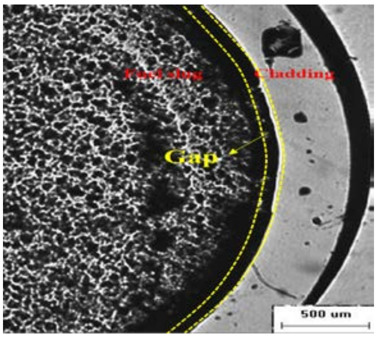

Fig. 2. Microscope photograph of U-10Zr-5Ce/T92 specimen after heating test (800 °C, 1 hr).

In order to investigate the microstructure of eutectic melting region in detail for U-10Zr/T92 specimen, constituent distributions and eutectic penetration depth were measured by utilizing SEM and EPMA (Fig. 3). As shown in Fig. 3, it was observed that U and Zr components penetrated into cladding region, and Fe component slightly penetrated into fuel slug region at the eutectic melting region. Also, it was observed that Nd lanthanide fission product penetrated into cladding region. It is reported that lanthanide fission products such as Nd, Ce, La, Pr and Sr migrate into fuel slug-cladding interface during irradiation step, and lower the eutectic threshold temperature, so that eventually, promote the eutectic reaction between fuel slug and cladding. The measured maximum eutectic penetration depth along cladding direction during 1 hr was 115 μm and the penetration rate was calculated to be 0.032 μm/sec. This measured penetration rate is almost similar to prediction value (0.026 μm/sec) by existing eutectic penetration rate correlation being used for design and modelling purposes. These results are presented in Fig. 4 along with experimental results of penetration rate reported in the literatures [2,3].

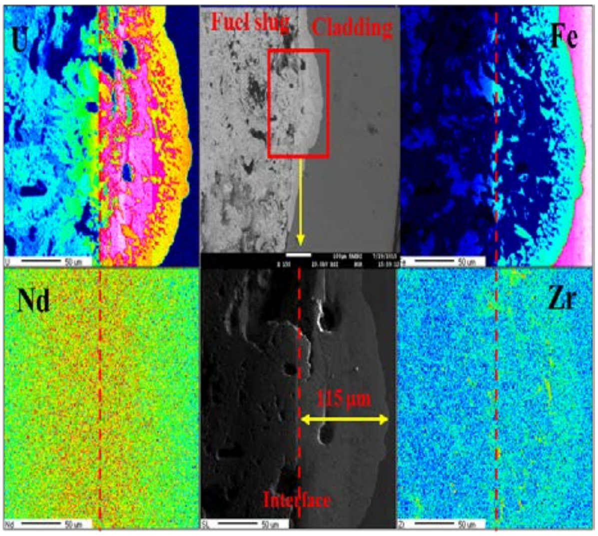

Fig. 3. Constituent distributions and eutectic penetration depth of U-10Zr/T92 specimen after heating test (750 °C, 1 hr).

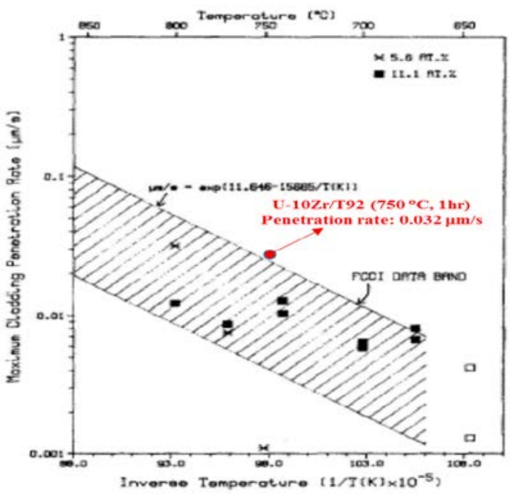

Fig. 4. Maximum eutectic penetration rate along cladding direction.

4. Conclusions

Microstructure of the irradiated U-10Zr and U-10Zr-5Ce fuel slug with T92 cladding after high-temperature heating test were investigated through the microscope, SEM and EPMA. Also, the measured maximum eutectic penetration rate along cladding direction was compared with the prediction value by existing eutectic penetration correlation. In the case of U-10Zr/T92 specimen, migration phenomena of U, Zr, and Fe as well as Nd lanthanide fission product were observed at the eutectic melting region. The measured penetration rate was almost similar to prediction value by existing eutectic penetration rate correlation.

In the future, high-temperature heating tests will be additionally performed as for the irradiated U-10Zr and U-10Zr-5Ce fuel slugs with HT9 and FC92 cladding in order to compare difference of microstructure and eutectic penetration rate according to cladding types.

ACKNOWLEDGEMENT

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REFERENCES

[1] Alan E. Waltar, Donald R. Todd and Pavel V. Tsvetkov, “Fast Spectrum Reactors”, Springer, 2012.
[2] A. B. Cohen et al., “Fuel/Cladding Compatibility in High-Burnup U-19Pu-10Zr/HT9-Clad Fuel at Elevated Temperatures”, J. Nucl. Mat., Vol. 204, pp. 244-251, 1993.
[3] H. Tsai et al., “Behavior of Low-Burnup Metallic Fuels For the Integral Fast Reactor at Elevated Temperatures In Ex-Reactor Tests”, ANL/CP-71935, ANL, 1991.
[4] J. S. Cheon, “Post Irradiation Examination on SMIRP-1 Fuel Rods”, SFR-160-FP-458-001, KAERI, 2014.