Feasibility Study on Fabrication Technology for Transmutation Fuel with Surrogate Alloys

Jong-Hwan Kim*, Ki-Hwan Kim, Jung Won LEE, Seoung Woo Kuk,
Jeong-Yong Park, Jin-SiK Cheon, Sung-Ho Kim

Korea Atomic Energy Research Institute, 111,Daedeok-daero 989 beon-gil, Yuseong-gu, Daejeon, Korea, 305-353
**Corresponding author: jhk9@kaeri.re.kr*

1. Introduction

Current research and development activities on metallic fuel are focused on its potential use for TRU transmutation in fast reactors. This fuel transmutes the long-live transuranic actinide isotopes contained in spent nuclear fuel into shorter-lived fission products. Therefore, it can dramatically decrease the volume of material requiring disposition as well as the long-term radiotoxicity and heat load of high-level waste sent to a geologic repository [1, 2].

The technology for fabricating transmutation fuels has existed and has continued to be upgraded and refined over the past several decades. The development of the metallic fuel is more advanced than the other fuel forms such as ceramic or dispersion (either CERCER or CERMET). Metallic fuel has many advantages such as simple fabrication procedures, good neutron economy, high thermal conductivity, and acceptable compatibility with the cladding and reactor coolant, as well as low swelling caused by fission products.

Fuel fabrication technologies should be specifically engineered with the desired properties. There are certain material constraints, such as those created by fuel cladding and fuel element operating conditions as well as the environment. Technology for metallic fuel has been developed by various methods such as rolling, swaging, wire drawing, and co-extrusion, but each of these methods has had process limitations requiring an additional subsequent process. The fabrication equipment is complex and is not favorable for remote use. The practical process of metallic fuel fabrication needs to be cost efficient, suitable for remote operation, and capable of mass production while reducing the amount of radioactive waste.

In this study, a preliminary feasibility study was carried out on particulate-pack and injection casting with a surrogate alloy as fabrication technology for the transmutation fuel.

2. Metallic Particulate Pack

Metallic particulate fuel is one of the most innovative fuel forms for the transmutation in fast reactors, as it combining the favorable features of both metal and MOX fuel [3, 4]. Its major advantages are the fabrication for any shaped fuels and the simplification of the process with sodium-free fuel. Thus, various innovative packing methods of nuclear fuel powder have been studied to develop particulate fuel.

To evaluate the fabrication technology for the metallic particulate fuel, a vibration packing system for an electronic dynamic shaker was installed with the feeding apparatus of the metal powder (Fig. 1). The vibration packing test for the metallic particulate fuel has been performed systemically based on the literature research.

Spherical SUS 316L powder was used as a surrogate alloy for the radioactive TRU-bearing material, and Figure 2 shows the powder classified by the sieve analysis. The fabricated particulate fuels were characterized with packing density measurements and an X-ray CT micrograph.

The results showed that in the case of the packing conditions such as premixed power and continuous infiltration filling, it is possible to fabricate an entirely homogeneous fuel that has packing densities ranging from 67% to 78% (75% in recycling fuel). The important packing parameters that affect the soundness of the particulate fuel are considered as follows:

(i) Particle mixing
(ii) Loading method
(iii) Frequency
(iv) Acceleration
(v) Rate of frequency sweeping

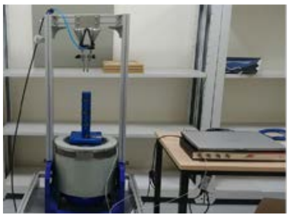

Fig. 1. Vibration packing system with the feeding apparatus of the metal powder.

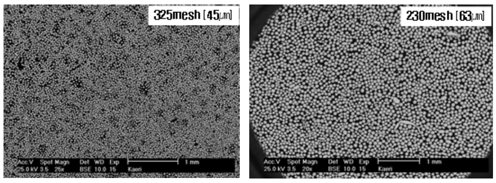

Fig. 2. Morphologies of the atomized SUS 316L powder

3. Injection Casting

Injection casting is one of the processes that meet those needs as fabrication technology for metallic fuel. It also has strong advantages in terms of fabricating small-diameter castings with a high L/D ratio and a randomly oriented grain structure, which result in precision castings [5, 6].

For the fabrication feasibility study, a surrogate U-Zr slug, which is defined as an un-encapsulated, as-fabricated piece of metallic fuel, was prepared using a lab-scale induction furnace. The alloy component Zr was increased from 15wt% up to 25wt%.

Induction heating was selected as the melting technology in this study because it can be designed to provide intense metal stirring. It is also adaptable to a wide variety of casting techniques and crucible materials. The surrogate alloys were heated by induction heating at a frequency of 3 kHz and a maximum power of 30 kW in the upper chamber. When the crucible temperature reached approximately 200°C higher than the melting point, the alloy melt was held and stirred electromagnetically by applying an induction heating cycle from 0% to 100% to ensure the homogeneity of the melt. The flow of the molten material was driven into the quartz mold by the pressure of argon.

The prepared slug was cut into slices of a suitable thickness using a slow-speed diamond cut-off wheel, whose density was measured using the Archimedean immersion method. The microstructures were analyzed using scanning electron microscopy (SEM) with energy-dispersive X-ray spectroscopy (EDX). The chemical composition of the fuel slugs and the presence of impurities were assessed by the inductively coupled plasma atomic emission spectrometry (ICP-AES).

The appearance of the typical slug (U-25wt%Zr) is shown in Figure 3. The surfaces in the middle and upper regions of the slugs are smooth and the surfaces are somewhat rough in the lower region where the quartz mold merged with the melt and some reaction layers were observed. However, the integrity of as-cast slugs was believed to still be satisfactory because both ends of the castings were cut off using a shearing device in a subsequent process.

Fig. 3. Photograph of a U-15wt%Zr slug fabricated by injection casting

Figure 4(a) shows a secondary electron SEM image with the area from which the EDS spectra were acquired. The measured composition is high in Zr with a small amount of dissolved U, indicating that these phase are Zr-rich inclusions (Fig. 4(b)).

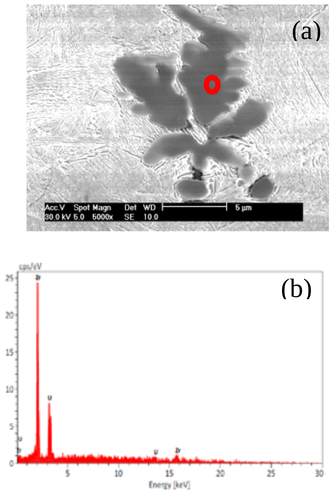

Fig. 4. SEM image of U-15 wt%Zr (a) and EDX spectra at the precipitation (b)

3. Summary

As a preliminary feasibility study on fuel fabrication technologies for transmutation fuels, metallic particulate pack and injection casting were carried out. Packing conditions such as premixed power and continuous infiltration filling showed the homogeneous fuels having packing densities ranging from 67% to 78%. The surrogate slugs with a high content of Zr (~25wt%) were fabricated by injection casting, which was equipped with an induction heating system. They had a full length of the mold and showed a sound appearance.

4. References

[1] Report to Congress on Advanced Fuel Cycle Initiative: Objectives, Approach, and Technology Summary, U.S. Department of Energy Office of Nuclear Science and Technology, May 2005.

[2] Report to Congress on Advanced Fuel Cycle Initiative: The Future Path for

[3] M.A. Pouchon, G. Ledergerber, F. Ingold, K. Bakker, Comprehensive Nuclear Materials, Num. 3, 275-312, 2012

[4] G. Ledergerber, F. Ingold, R.W. Stratton, H.P. Alder, Nucl. Technol. 114, 194–204, 1996

[5] Stevenson CE (1987) The EBR-II Fuel Cycle Story. American Nuclear Society

[6] Burkes DE, Fielding RS, Porter DL, Crawford DC, Meyer MK (2009) J Nucl Mater 389:458-469