Fabrication of Particulate Metal Fuel for Fast Burner Reactors

Ho Jin Ryu*, Sun Yong Lee, Jong Hwan Kim, Yoon Myung Woo, Young Mo Ko, Ki Hwan Kim, Jong Man Park, Chan Bok Lee
Korea Atomic Energy Research Institute: 1045 Daedeok-daero, Yuseong-gu, Daejeon 305-353, Republic of Korea
Corresponding author: hjryu@kaeri.re.kr

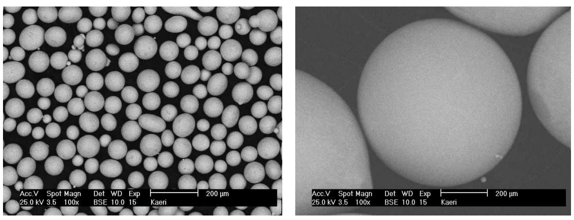
1. Introduction

U-Zr metallic fuel for sodium-cooled fast reactors is now being developed by KAERI as a national R & D program of Korea. In order to recycle transuranic elements (TRU) retained in spent nuclear fuel, remote fabrication capability in a shielded hot cell should be prepared. Moreover, generation of long-lived radioactive wastes and loss of volatile species should be minimized during the recycled fuel fabrication step. Therefore, innovative fuel concepts should be developed to address the fabrication challenges pertaining to TRU while maintaining good performances of metallic fuel. Particulate fuel concepts have already been proposed and tested at several experimental fast reactor systems and vipac ceramic fuel of RIAR, Russia is one of the examples [1]. However, much less work has been reported for particulate metallic fuel development [2,3].

Spherical uranium alloy particles with various diameters can be easily produced by the centrifugal atomization technique developed by KAERI [4]. Using the atomized uranium and uranium-zirconium alloy particles, we fabricated various kinds of powder pack, powder compacts and sintered pellets. The microstructures and properties of the powder pack and pellets are presented.

2. Experimental procedures

Spherical pure uranium particles and U-10wt%Zr alloy particles were fabricated by centrifugal atomization at 1400-1500^{o}C. By adjusting the rotating speed of the spinning disk of the atomizer, U-10wt%Zr powder with bimodal size distribution was obtained. The size distribution of the atomized powder was measured by sieve classification. Green compacts of atomized uranium powder were fabricated by the addition of second element powder including Ti, Mo, Cr, and Zr.



(a) (b)

Fig. 1. Atomized U-10wt%Zr powder; (a) fine U-10Zr powder, (b) coarse U-10Zr powder.

The compacts of mixed powder were sintered at 1000^{o}C for 5 hours under vacuum. Cross-section microstructures of sintered pellets were observed by using scanning electron microscopy.

3. Results and discussion

In addition to the high fabrication efficiency, it is expected that particulate U-Zr fuel has lower fuel-cladding mechanical interaction owing to free restructuring during irradiation. The microstructures of atomized U-10wt%Zr particles were shown in Fig. 1. The average sizes of fine powder and coarse powder were about 70 μm and 350 μm, respectively, as shown in Fig. 2. The packing densities of the mixed powder were measured with the varying mixing ratio of the fine powder to the coarse powder. Having a pellet-type fuel has several advantages in fuel performance and fuel handling. In case of accident such as a cladding breach, consolidated fuel has more safety features than particulate fuel in terms of the release of fissile materials and fission products. Therefore, it is important to confirm the feasibility of pelletizing of particulate uranium alloy powder, because it is hard to get green pellets by using spherical particles without binders. There are several attempts to fabricate metallic fuel using particulate uranium for fast burner reactor fuel.

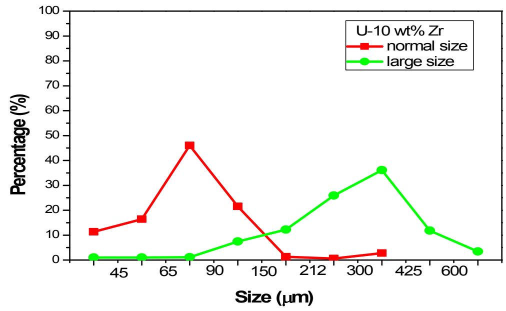
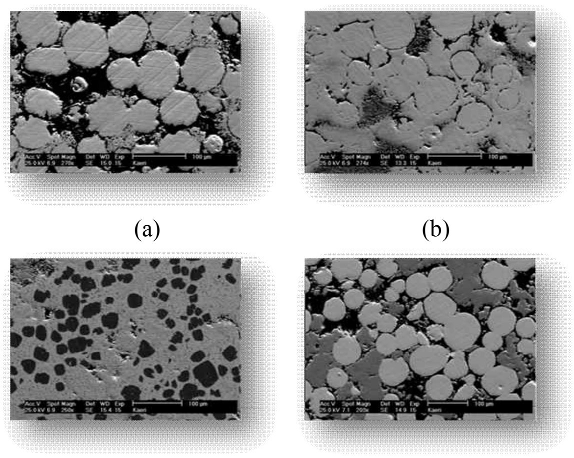


Fig. 2. Comparison of the size distribution of atomized U-10wt%Zr powder.

Fig. 3. Green compacts of metallic uranium powder with the addition of 30 vol.% of molybdenum (left) and chromium (right).

Molten metal infiltration of low melting temperature zirconium alloys was tested to fabricate uranium alloy powder dispersion fuel in Russia [3]. In the US, there is an attempt to fabricate fully sintered uranium alloys by using very fine uranium powder [5]. It was found that green compacts of uranium alloy powder could be obtained by the addition of secondary element powder to the uranium alloy powder at least 30 vol.%. The neutron absorption and activation of the secondary elements should be low and Cr, V, Mo, and Ti are candidate elements. Various secondary elements were tried as shown in Fig. 3 and some of them were sintered at 1000°C for the fabrication of loosely sintered pellets.

Fig. 4 shows the cross-section microstructures of sintered samples with varying second elements. When interdiffusion of each element was active, a skeleton structure of powder was developed as in U-Mo. The microstructure of a U-Cr mixed powder pellet shows a hint of solidification because their eutectic melting temperature is below 1000°C. A surface morphology of uranium-chromium mixed powder pellet after sintering was shown in Fig. 5. Bonding of particles was not active in U-Ti and U-Zr mixed powder pellets, mainly because of their limited interdiffusion at the sintering temperature. When the secondary phase forms a continuous network, the thermal conductivity of particulate fuel will be enhanced. In addition, the use of sodium bond in the metal fuel cladding can be eliminated so that the handling of spent fuel containing radioactive sodium could be simplified.



(a) (b) (c) (d)

Fig. 4. Cross-section microstructures of sintered pellets with varying second elements after sintering at 1000°C for 5 hours: (a) U-Ti, (b) U-Mo, (c) U-Cr, (d) U-Zr.

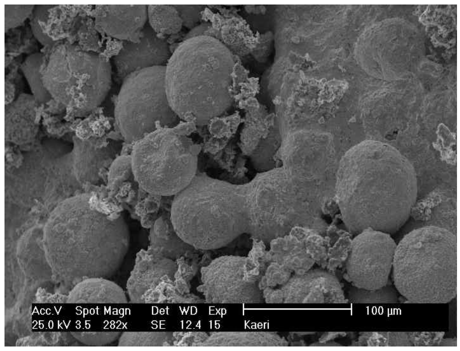


Fig. 5. A surface morphology of uranium-chromium mixed pellet after sintering at 1000°C for 5 hours.

4. Conclusions

- Metallic uranium and U-10wt%Zr powder with diameters ranging from 20 to 600 μm were fabricated by a centrifugal atomization technique.
- Green compacts of metallic uranium powder with the addition of 30 vol.% secondary elements including Ti, Mo, Cr and Zr were fabricated.
- Porous pellets of metallic uranium powder and mixed powder containing secondary elements were fabricated by sintering under vacuum.
- The microstructures and properties of the sintered pellets using uranium alloy particles were compared to estimate their fabrication efficiency and fuel performance.

ACKNOWLEDGMENTS

This study was supported by the National Nuclear R&D Program of the Ministry of Education, Science and Technology (MEST) of Korea. The authors are grateful for the fabrication of atomized U and U-Zr particles by the Research Reactor Fuel Division of KAERI.

REFERENCES

[1] R. Herbig et al., J. Nuclear Materials, **204** (1993) 93.
[2] L.Walters et al., ICAPP-2010, San Diego, June 13-17, 2010
[3] A.M. Savchenko et al., J. Nuclear Materials, **385** (2009) 148.
[4] C.K.Kim et al., Nuclear Engineering and Technology, **39** (2007) 617
[5] S. McDeavitt, NERI-Report, 2011.