Porous U-10Zr fuel pellet fabrication using spark plasma sintering

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1. Introduction

Metal fuel, especially U-Zr alloys are attractive candidate material for fast reactor since it can provide high fissile density, high thermal conductivity, and a negative reactivity factor. However, low smear density (~75%) and accompanied sodium bonding is required due to its higher swelling rate [1]. The application of sodium bonding would increase not only the fuel fabrication cost but also difficulties in the storage and reprocessing of spent nuclear fuel. One potential alternative to sodium bonding is mechanical bonding using porous metal fuel, which could offer comparable heat transfer and smear density at the same time.

Conventionally, porous metal fuel has been made with powder metallurgy process [2], which can easily control the fuel density. Spark plasma sintering (SPS) is advanced powder metallurgy technique using high energy pulsed DC current to powder, which generates plasma heating that result rapid densification. Recently, the potential of SPS for the fabrication of porous metal fuel has been investigated [3].

In this study, I explored the feasibility of fabricating high porosity U-10Zr fuel pellets through powder metallurgy and spark plasma sintering.

2. Methods and results

2.1 Uranium powder production

Metal uranium powder was produced using hydride-dehydride process from bulk metal uranium, as following equation [4]:

$$2U + 3H_2 \leftrightarrow 2UH_3$$

Bulk depleted metal uranium (DU) surfaced was cleaned using 60% nitric acid. As-cleaned DU was placed in an Al_2O_3 crucible and heated in a glovebox connected tube furnace at 235°C for 8 hours in a H_2 (99.99%) atmosphere. The bulk metal uranium was converted to brittle UH_3 pieces and pulverized using agate mortar and pestle. To dehydride the UH_3 powder to uranium powder, it was loaded into Al_2O_3 crucible and heated in a glovebox furnace at 430 ℃ under 10^{-2} torr vacuum pressure for 10 minutes. As a result, silverish uranium metal powder with 30-70 μm particle size was obtained (Fig. 1.).

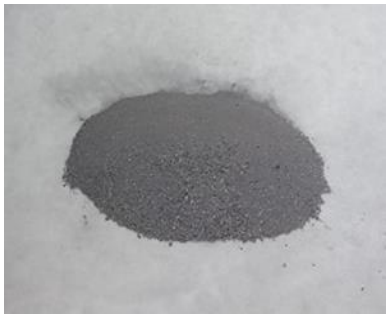

Figure 1. Visual image of metal uranium powder obtained using hydride-dehydride process.

2.2 U-10Zr pellet fabrication using SPS

A SPS apparatus (DrSinter, SPS-211LX) was used for the pellet fabrication. The uranium powder and zirconium powder (99.9%, ~1 μm, Avention) was blended with 90:10 weight ratio using 3d blender and loaded into 10 mm inner diameter cylindrical graphite mold. The U-10Zr pellet was sintered at 600 °C for 1 hours under 20 MPa uniaxial pressure and 0.3 torr vacuum pressure. The temperature was increased at a rate or 100 °C/min. Figure 2 shows the as-fabricated U-10Zr pellet SPSed at 600 °C for 10 minutes. The density of SPSed pellet was measured using Archimedes immersion method and revealed about 78% of theoretical density.

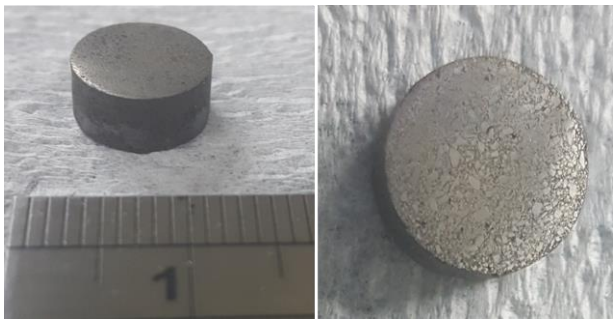

Figure 2. Visual image of U-10Zr pellet SPSed at 600 °C for 10 min.

2.3 Microstructure

The microstructure of SPSed U-10Zr pellet was investigated using scanning electron microscopy (SEM, EM30ax plus, COXEM) and energy dispersive X-ray spectrometry (EDS). The backscattered SEM image (Fig. 3) showed bright U phase with different particle size from 10 to 100 μm, dark Zr phase surrounding the

U particle, and pore. Zirconium phase tended to be located along U particle and grain boundary. The pores were mainly observed only in Zr phase, due to the higher sintering temperature of Zr than that of U. It is noted that the SEM image showed excessively dense microstructure compared to the measured relative density.

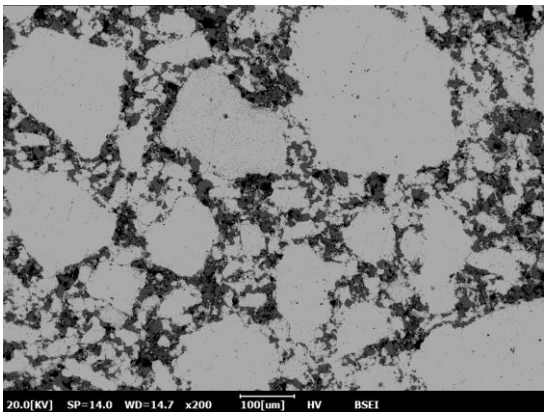

Figure 3. SEM/BSE image of SPSed U-10Zr pellet.

The EDS mapping analysis showed no evidence of the formation of intermetallic compound such as δ-$dUZr_2$, which is expected due to lower sintering temperature (600 °C) and short sintering time (10 min).

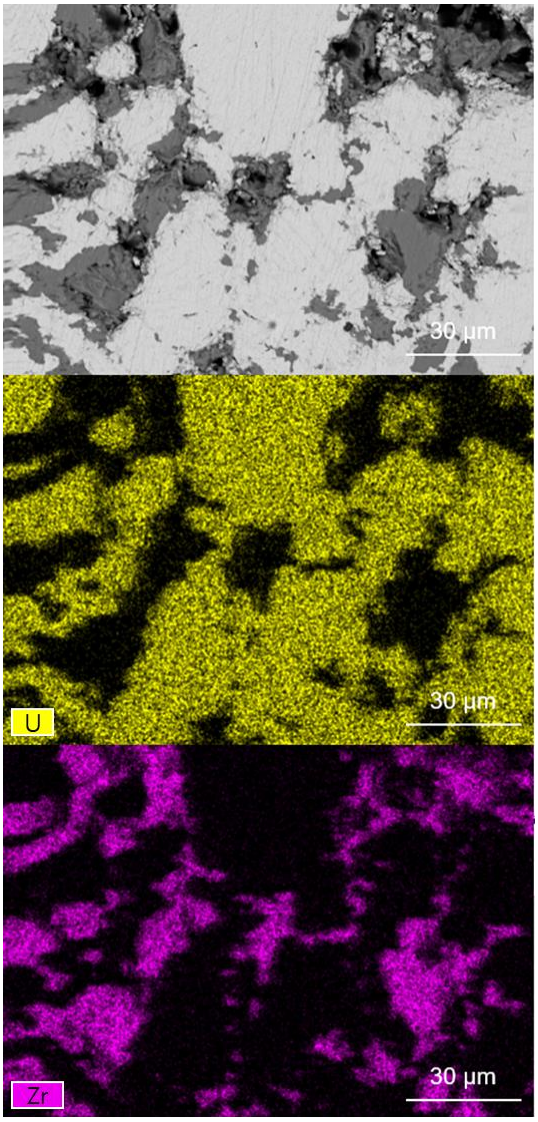

Figure 4. EDS mapping analysis on SPSed U-10Zr pellet.

3. Conclusion

The feasibility of fabricating high porosity U-10Zr fuel pellets through powder metallurgy and spark plasma sintering method was investigated. A U-Zr mixed powder with a weight ratio of 90:10 was successfully sintered using SPS at 600 °C for 10 min without noticeable formation of impurity and intermetallic phase. Further investigation on different sintering temperature and Zr composition will be conducted to ensure the metal fuel fabrication capability. Additionally, the comprehensive analysis will be performed to determine the reasons for the mismatch between measured density and microstructure.

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