Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 9-10, 2024

Fabrication of annular metal fuel pellet using powder metallurgy process

Jungsu Ahn[a], Sang-Gyu Park[a], Jun Hwan Kim[a]
[a]*KAERI, Advanced Fuel Technology Development Division, Deogjin-dong, 111, Daedeok-daero 989 beon-gil, Yuseong-gu, Daejeon, Korea**
[*]*Corresponding author: ajs@kaeri.re.kr*

1. Introduction

Metal fuels offer superior stability and economy compared to conventional nuclear fuels due to their high thermal conductivity and fissile density. However, ensuring thermal margin due to the relatively low melting point of metal fuels necessitates maintaining heat transfer within the fuel rod, potentially requiring additional manufacturing processes such as sodium bonding, which could compromise fuel fabrication yield. Annular metal fuel technology is one solution to address these challenges, which could maintain fuel smeared density while simplifying the nuclear fuel manufacturing process.

In this study, powder metallurgy was employed to manufacture annular metal fuel with a U-10wt.%Zr composition. Annular metal fuel pellets were fabricated using cold pressing method and spark plasma sintering (SPS) method, respectively. The feasibility of sintering variables was evaluated by conducting visual inspection, density measurement, and microstructure and phase analysis on the fabricated pellets.

2. Methods and Results

Metal uranium ingots underwent hydride-dehydride processes to produce DU powder with sizes ranging from 1 to 30 μm, with the reaction as follows [1].

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

Manufaturing of annular metal furl pellet was carried out uisng two different methods: 1) cold sintering, and 2) spark plasma sintering (SPS). Metal uranium powder was mixed with zirconium powder (100-150 μm) with 9:1 weight ratio. The uranium-zirconium mixed powder was then compacted under a pressure of 20 MPa for one minute using a graphite mold designed for annular pellet production. Due to the low viscosity of uranium powder, the resulting compacts could not maintain their shape after ejection, hence they were directly sintered without ejection. Sintering was conducted in an argon gas atmosphere (20 ml/min) at temperatures ranging from 800 to 1100 °C for 8 hours each. The sintered pellets obtained had an outer diameter of 10 mm, inner diameter of 6 mm, and height of 10 mm, with numerous pores observed upon visual inspection. The sintered pellets exhibited very low sintering densities, reaching only 55% of theoretical density at 800 °C and 58% at 1000 °C. Microstructural observations revealed minimal densification of the Zr powder, indicating that the sintering temperature was insufficient. Further evidence was revelaed by SEM images showing numerous pores between the Zr powder and U matrix. Despite increased sintering temperature (1100 °C), densification was still inadequate, with partial melting and coalescence occurring within the pellets due to the high temperature.

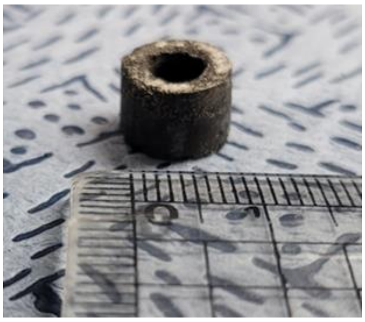

Fig. 1. Annular U-10Zr fuel pellet fabricated by cold sintering.

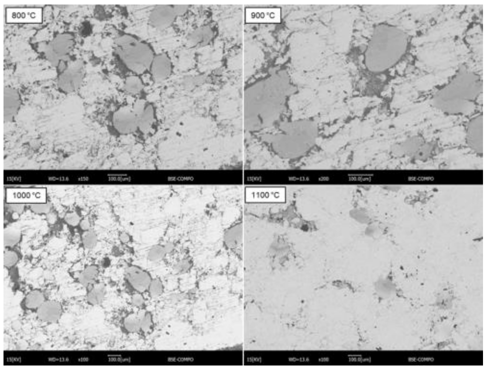

Fig. 2. SEM image of U-10Zr fuel pellet fabricated by cold sintering.

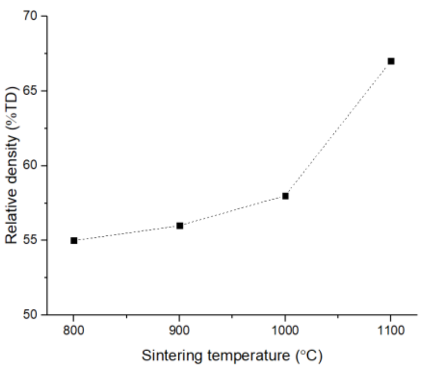

Fig. 3. Relative density of annular U-10Zr fuel pellet fabricated by cold sintering.

Spark Plasma Sintering (SPS), a high-performance sintering technique, was also applied to the manufacture of annular metal fuel. DU powder (1-30 μm) was mixed with three types of Zr powder with particle size of 100-150 μm and weight ratio of 9:1. The mixture was then placed into graphite molds designed for SPS and wrapped with graphite paper to facilitate easy ejection after sintering. The molds were placed in a sintering chamber under vacuum (1x10^{-2} torr) and sintered under a pressure of 20 MPa for 5 minutes. Sintering was conducted within the temperature range of 600 to 900 °C. The sintered pellets obtained had outer diameters of 10 mm, inner diameters of 6 mm, and heights ranging from 5 to 10 mm.

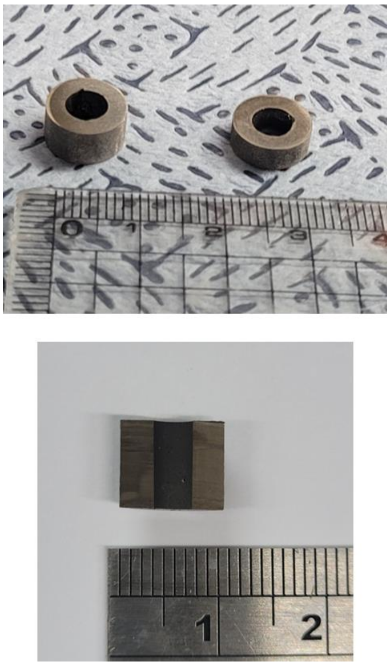

Fig. 4. Annular U-10Zr fuel pellet fabricated by SPS.

Microstructural observations and compositional analysis were performed on the obtained pellets. The microstructural analysis revealed that the finely dispersed Zr was found within the U matrix and incomplete densification around the large Zr particle.

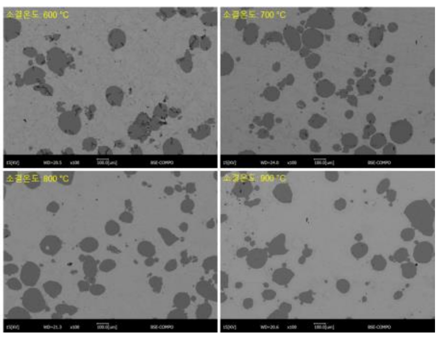

Fig. 5. SEM image of U-10Zr fuel pellet fabricated by SPS.

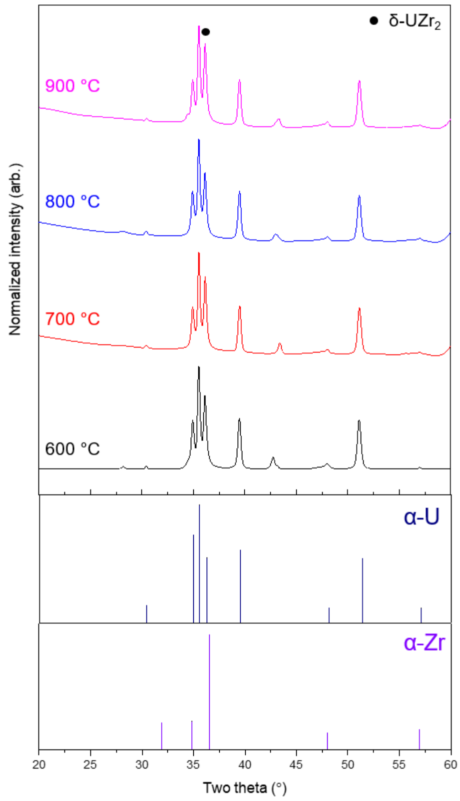

Fig. 6. XRD analysis on as-sintered U-10Zr fuel pellet fabricated by SPS

3. Conclusions

Annular metal fuel pellets with U-10wt.%Zr composition were fabricated through both cold pressing and spark plasma sintering methods. Fuel pellet produced using cold pressing exhibited high porosity and low density due to low sinterability and high sintering onset temperature of zirconium. Metal fuel pellets produced by spark plasma sintering method showed low porosity despite short sintering time (5 minutes) and low sintering temperatures (600-900 °C).

Acknowledgments

This work was supported by the National Nuclear R&D program funded by Ministry of Science and ICT (2021M2E2A2081066).

REFERENCES

[1] W.M. Mueller, J.P. Blackledge and G.G. Libowitz, “Metal Hydrides”, Academic Press, 1968.