Application of 3D Printing Process for Fabrication of ZrO_2-Zr_2Cu Composite Fuel

Seong-Jun Ha [ab], Young-Kook Lee [a], Kyung-Chai Jeong [b], Seok-Jin Oh [b], Hyun Gil Kim [c], Jeong-Yong Park [d*]
[a]*Department of Materials Science and Engineering, Yonsei University, 03722 Seoul, Korea*
[b]*Next-Generation Fuel Technology Development Division, Korea Atomic Energy Research Institute, 34057 Daejeon, Korea*
[c]*Nuclear Fuel Safety Research Division, Korea Atomic Energy Research Institute, 34057 Daejeon, Korea*
[d]*Radwaste Transportation and Storage Research Team, Korea Atomic Energy Research Institute, 34057 Daejeon, Korea*
[*]*Corresponding author: parkjy@kaeri.re.kr*

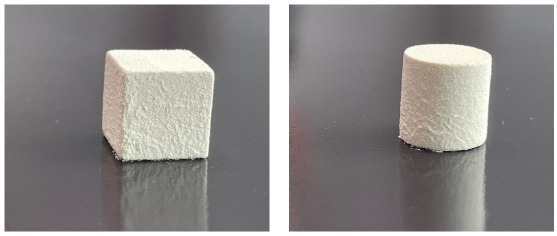
1. Introduction

Nuclear fuel is one of the most important components in nuclear applications considering safety and economy. Oxide fuel like UO_2 is used for commercial nuclear reactors among a variety of nuclear fuel types (metal, silicide, nitride, etc.). UO_2 fuel has a low thermal conductivity which results in detrimental effects in terms of plant safety, performance, etc. Thermal conductivity of the nuclear fuel could be improved by development of the composite fuel which contains a metal matrix. In previous studies, a variety of the composite fuels were studied such as UO_2-W and UO_2-Fe [1-2]. UO_2 particles in the composite fuel fabricated by hot isostatic pressing, spark plasma sintering, etc. could not be uniformly distributed. A uniform distribution of the fuel particles is mightily important as a composite fuel because it results in hot spots and ultimately leads to failure of the nuclear fuel.

In this study, additive manufacturing (AM) with subsequent pressureless melt infiltration was introduced to fabricate the composite fuel with a uniform distribution and various forms. Preform was fabricated using ZrO_2 powder as a surrogate of UO_2 by binder jet process. The melt infiltration using Zr_2Cu alloy was carried out as a follow-up process to fabricate the composite fuel. Additionally, microstructure of the ZrO_2-Zr_2Cu composite fuel was investigated to evaluate the fabrication of the composite fuel.

2. Methods and Results

As shown in Fig. 1, ZrO_2 preforms with a cubic (10 x 10 x 10 mm) and cylinder (D10 x h10 mm) forms were printed by binder jet processing. Several processing parameters for printing the preform were listed in Table 1. ZrO_2 powders with a diameter of 30 μm (D50) were used and it was stacked with a thickness of 100 μm. The preforms were shaped as cubic and cylinder forms by saturating solvent-based binder and curried in an oven. Key parameters of the preform fabrication process by binder jet processing were identified as powder density, layer thickness, and binder saturation.



(a) (b)

Fig. 1. ZrO_2 preforms printed by binder jet processing; (a) cubic and (b) cylinder forms

Table 1. Processing parameters of binder jet processed ZrO_2 preforms

Processing parameters	
Material	ZrO_2
Particle size	30 μm (D50)
Forms	Cubic, Cylinder
Binder	Aquafuse (Exone)
Desired saturation	40%
Layer thickness	100 μm

As shown in Fig. 2, the preform was heated up to 1200 °C for debinding and melt infiltration, and it was cooled in the furnace. Zr_2Cu alloy as a matrix material was used to infiltrate into the porous preform. Zr_2Cu alloy was spontaneously infiltrated from the bottom of the preform, and the composite was fabricated up to approximately 50% of the preform height. Only ZrO_2 particles with keeping the shape of preform remained in the uninfiltrated region.

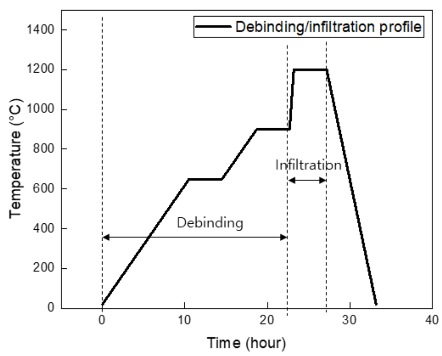


Fig. 2. Debinding/infiltration profile for binder jet processed ZrO_2 preform

Microstructure of the ZrO_2-Zr_2Cu composite was investigated by scanning electron microscopy (SEM). As shown in Fig. 3, Zr_2Cu alloy was infiltrated into the porous preform. A phenomenon in which Zr segregated to the surface of ZrO_2 particles was observed while the Zr_2Cu alloy was infiltrated into the ZrO_2 preform, and it was speculated that there would be an interaction at the interface between the ZrO_2 and Zr_2Cu during the infiltration process.

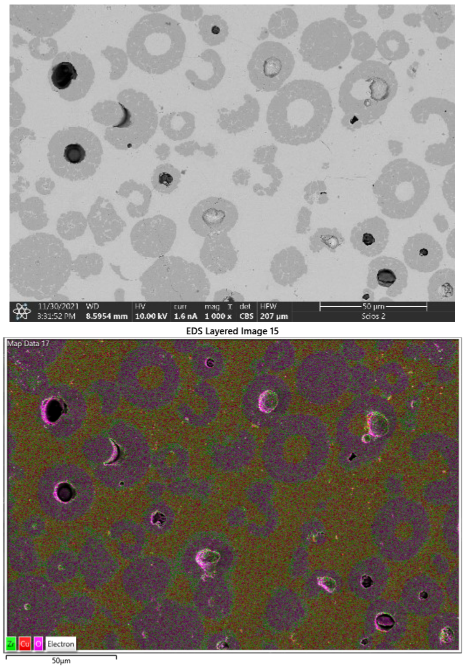


Fig. 3. SEM-EDS images of ZrO2-Zr2cu composite

3. Conclusions

In this study, ZrO_2-Zr_2Cu composite fuel was fabricated by applying a 3D printing process with the subsequent melt infiltration process. Zr_2Cu alloy could be spontaneously infiltrated into the ZrO_2 porous preform up to approximately 50% of the preform height. As a result, the fabrication of the composite fuel was positively evaluated. However, it is needed to improve infiltration by controlling the surface tension of matrix alloy or interfacial energy between matrix alloy and preform.

REFERENCES

[1] D.S. Tucker, CERMETS for use in nuclear thermal propulsion, Advances in Composite Materials Development, IntechOpen (2019).

[2] G. Arthur, J.A. Coulson, Physical properties of uranium dioxide-stainless steel cermets, J. Nucl. Mater. 13 (1964) 242-253