A Study on Innovative Metallic Fuel Shapes and Their Manufacturing Requirements

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1. Introduction

Improving economy and enhancing safety of sodium fast reactors require nuclear fuel with high power density and low pressure drop. Therefore, it has been proposed that an annular and bottle-shaped fuel by [1], which can maintain outstanding heat transfer performances and lower fuel temperature compared to conventional solid metallic fuels. In the case of annular nuclear fuel system including UO_2 annular pellet, enlarged Zr-based cladding, supporting structures, etc., systematic studies have been carried out for replacing conventional solid fuel with annular oxide fuel in operating PWRs in Korea [2-4]. The concepts of annular and bottle-shaped fuel for SFR show an increase of the power density by 20% in low-conversion ratio (burner) cores with metal fuels. Especially, annular metal fuel can survive a complete flow blockage of the hottest inner channel [1]. In this study, three types of metallic fuels which were not studied due to the difficulties of the manufacturability were proposed to evaluate their manufacturing requirements. The basic performance and their manufacturing requirements with complicated shapes have been examined. In particular, the recent development of additive manufacturing technology based on the 4th industry has reduced the production limits of complicated fuel shapes.

2. Reference Fuel Shapes

In this study, shapes for honeycomb, multi-hole and bamboo-wife structures were derived, and the expected performances are summarized in Table 1.

Table 1. Proposed concept of metallic fuel

Type	Honeycomb	Multi-hole	Bamboo-wife
Concept			

First, it is expected that all three shapes show excellent thermal conductivity and melting allowance, which is expected to have outstanding fuel performance when the gap conductance was used as simple conduction through the sodium bond. However, it is necessary to evaluate FCMI (Fuel Cladding Mechanical Interaction) and FCCI (Fuel Cladding Chemical Interaction) for application of barrier cladding. In order to prevent swelling, the smear density should be maintained below 75% and element redistribution should be verified.

3. Manufacturing Requirements

For manufacturing above complicated metallic fuel shapes, it is difficult to apply the conventional manufacturing process such as casting. Recently, the breakthrough of additive manufacturing technology enables to manufacture complicated fuel shapes that were almost impossible with conventional methods. Among various methods, two kinds of additive manufacturing (i.e., selective layer sintering (SLS) and direct energy deposition (DED)) can be applied to innovative metallic fuel as shown in Fig. 1 and their specifications can be referred in previous literature [5]. Table 2 summarized effective manufacturing methods of each fuel shape with the consideration of manufacturing requirements.

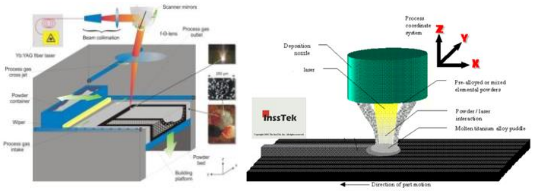

Fig. 1. Typical additive manufacturing methods; (left) SLS, (right) DED.

Table 2. Summary of manufacturing requirement

Type	Honeycomb	Multi-hole	Bamboo-wife
Methods	SLS, DED	Conventional casting or extrusion	SLS, DED
Manufacturability	High	Low	High
Raw material	Powder	Any	Powder
Loss during manufacturing	Low(SLS) High (DED)	Low	Low(SLS) High (DED)

Consequently, it is difficult to manufacture complicated fuel shapes using U or TRU powder by any additive manufacturing method. This is because one of the key factors determining the application of additive manufacturing to complicated metallic fuel shapes is to handle and manufacture TRU, U and Zr powders for supplying powder bed in SLS process and nozzle in DED process. Therefore, the additive manufacturing should be an auxiliary methods for making complicated metallic fuel.

4. Summary

In order to develop innovative metallic fuels with improved economy and enhanced safety of SFR, it is necessary to develop powder manufacturing technology for applying additive manufacturing technology.

ACKNOWLEDGEMENT

This work was supported by the National Research Foundation of Korea funded by the Ministry of Science and ICT (2017M2A8A5014888).

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