Fabrication of Metallic Particulate Fuel by Frequency-variable Electrodynamic Vibration

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1. Introduction

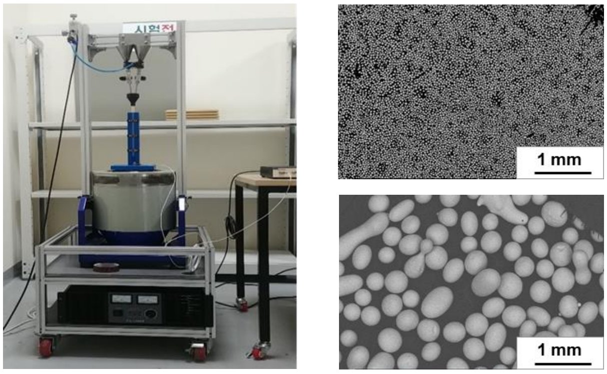
U-Zr alloy system fuel for a Gen-IV nuclear reactor has been developed in combination with the pyro-electrochemical processing of spent fuel. To recycle TRU (: Transuranic elements) retained in spent nuclear fuel, a remote fabrication method in a shielded hot cell should be prepared. Innovative fuel concepts, therefore, are required to address the fabrication challenges pertaining to TRU while maintaining good performances of metallic fuel. Metallic particulate fuel is an alternative form of conventional injection casting for metallic fuel slugs [1-3].

Spherical U-Zr alloy particles with continuous particle size distribution can be produced by the centrifugal atomization developed by KAERI [4]. Metallic particulate fuel has major advantages of the fabrication for any shaped fuels and the simplification of the process with sodium-free fuel, remote operation under high radioactive circumstance, accommodation of FCMI (: Fuel-Cladding Mechanical Interaction), high fission gas release and swelling.

In this study, a vibration packing method as an alternative fabrication of metallic particulate fuel was introduced in order to improve the injection casting for nuclear fuel. A metallic particulate fuel was preliminary fabricated by means of the vibration packing system, which utilizes a surrogate SUS316L powder, in order to evaluate the feasibility of fabricating a sound fuel possessing a packing fraction of 75% in weight.

2. Methods and Results

A vibration packing apparatus of the metallic particulate fuel was composed with a frequency-variable electrodynamic vibration shaker, a feeding system of metallic powder, and a simulated fuel rod jacket (Fig. 1-(a)). Spherical 316L stainless steel powder was prepared by a gas atomization method as a surrogate powder of the atomized U-Zr fuel powder (Fig. 1-(b)). The stainless steel powder was classified using a vibratory sieve shaker. Some steel particles were mechanically pre-mixed over total particle size to have similar size distribution of the atomized U-Zr fuel powder. Table 1 shows the spherical particle size distribution of the stainless steel powders vibro-packed into the metallic particulate fuel. The prepared stainless steel powder was vibro-packed into a simulated fuel rod. The packing density of the dummy fuel rod was evaluated by weighing the mass of the surrogate powder after vibro-packing and calculating the space volume in the fuel rod. After loading, the homogeneity of the vibratory compacted fuels was examined by nondestructive techniques by X-ray radiography to verify the uniformity of the fuel rod.



(a) (b)

Fig. 1. Frequency-variable vibration packing system (a), spherical SUS 316L metal powder (upper part: < 325mesh, lower part: < 50mesh) (b).

Table 1. Particle size distribution of powder groups blended after sieving of spherical 316L stainless steel powder.

Type of powder / Particle size (㎛)	Pre-mixed powder (wt.%)	Coarse powder (150-600 ㎛, wt.%)	Medium powder (45-150 ㎛, wt.%)	Fine powder (<45 ㎛, wt.%)
425 - 600	12.0	17.1	-	-
300 – 425	59.8	83.4	-	-
90 – 150	8.3	-	13.7	-
63 - 90	7.4	-	19.7	-
45 - 63	5.8	-	66.1	-
45 >	6.8	-	-	100

The vibration packing result of the simulated fuel rods according to packing condition was shown in Table 2. The fuel rod packed with the pre-mixed powder showed a homogeneous state with a packing fraction of 76.9% in weight. The fuel rod infiltrated with fine powder after the parallel filling of coarse and medium powder also revealed an inhomogeneous state in part with a packing fraction of 73.9% in weight. The fuel rod infiltrated with the continuous sequence of coarse powder, medium powder, and fine powder generally had an inhomogeneous state over total length part with a packing fraction of 65.1% in weight. The packing fraction of the simulated fuel rods was widely distributed ranging from 65.1% to 76.9% upto 11.8% in maximum according to the packing method. The filling method of the pre-mixed power and the infiltration filling method after parallel filling can be promising methods for the particulate fuel rods manufactured with smear densities corresponding to 75% in weight of theoretical density (TD).

Table 2. The vibration packing result of the simulated fuel rods according to packing condition.

Packing method \ Packing result	Packing density (g/cm^3)	Packing fraction (%)	X-ray radiography
Filling of pre-mixed power	6.00	76.9	Slight low- density segregation in both ends
Infiltration filling after parallel filling	5.76	73.9	Some low-density segregations in top region
Continuous infiltration filling	5.08	65.1	Entire low-density segregations over all

(a)
(b)
(c)

Fig. 2. X-ray radiography of the simulated sphere-packed fuel rods; (a) filling of pre-mixed power, (b) infiltration filling after parallel filling, (c) continuous infiltration filling.

X-ray radiography of the sphere-packed fuel rods was shown in Fig. 2. The fuel rod packed with the pre-mixed powder exhibited a slight low-density distribution in top and bottom side of the fuel rod with maximum length of 15mm in total length. It was thought that the fine particles in the fuel rod are difficult to reaching the bottom part during vibration packing, leading to some lack of fine particles in the end regions. The fuel rod infiltrated with fine powder after parallel filling of coarse and medium powder showed some low-density segregations in the top region of the fuel rod in the length of about 25mm. It was assumed that fine particles in the top part of the fuel rod manage to move toward the bottom region by the infiltration, resulted in some lack of fine particles in top region. The fuel rod infiltrated with the continuous sequence of coarse powder, medium powder, and fine powder revealed an entire low-density segregation in the simulated fuel rod over all. The fine particles in the top part of the fuel rod managed to move toward the bottom region during continuous infiltration filling, resulted in some lack of fine particles in top region like the infiltration after parallel filling. The portion of the sound fuel rod over the full length was largely different according to the packing method. The packing methods showing the sound state of the fuel rod revealed the filling method of the pre-mixed power and the infiltration filling method after parallel filling.

3. Conclusions

A vibration packing was introduced to the fabrication method of metallic particulate fuel as an alternative form of conventional injection casting for metallic fuel slugs. Metallic particulate fuel was preliminarily fabricated by means of the vibration packing system, using a surrogate spherical SUS316L powder, and examined to evaluate the feasibility of fabricating such fuel. Metallic particulate fuels possessing a packing fraction of between 65% and 75% were fabricated by vibration packing through the adjustment of the process parameters. The feasibility of the vibration packing method of nuclear fuel was preliminarily evaluated by performing the vibration packing composing of filling method of metallic powder and vibration condition.

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