Development of mold design of injection casting for annular fuel fabrication

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1. Introduction

The motivation for innovative fuel development is the development of the advanced ultra-high burnup sodium-cooled fast reactor metallic fuel concepts. The fabrication experiment seeks to investigate advanced fuel designs with the following features: decreased fuel smeared density (SD), venting of the fission gas to the sodium coolant, reduce the FCCI (Fuel Cladding Chemical Interaction), and an advanced fabrication method that includes consideration of annular fuel and extrusion method. The one of most attractive advantage of extrusion method is save the process waste by omitting the sodium process. From the previous study, annular fuel shows the possibility of the reduction of swelling effect and then prevention of the FCMI (Fuel Cladding Mechanical Interaction) [1, 2]. However, the extrusion fabrication technology of the annular fuel has not been developed yet. Therefore, KAERI has started to study the annular fuel fabrication method by using injection casting method.

This research manufactured and evaluated annular metal fuels with a composition of U-10wt.% Zr using injection casting. Based on previous injection casting studies conducted by KAERI, process variables were set and various quartz tube mold designs were used to fabricate annular metal fuel. After casting, the final production of annular metal fuel with a 6.40 mm outer diameter, 3.00 mm inner diameter, and a length of over 60 mm were successfully obtained.

2. Methods and Results

In order to manufacture a annular fuel of the target shape, a quartz tube with an inner diameter of 6.4 mm was manufactured by attaching a quartz column mold with an outer diameter of 3.0 mm (#1 quartz tube). In addition, to control eccentricity and defect occurrence, a support was attached to the internal mold pillar (#2 quartz tube) or a #3 quartz tube with the injection range shortened from 300 mm to 150 mm was used, and this was compared and evaluated with the existing experimental results. The inside of the quartz tube for injection casting was spray-coated with Y_2O_3 and then inserted into the flange. Afterwards, the prepared crucible and quartz tube assembly are charged into the induction heating chamber, an argon (99.99%) or vacuum atmosphere (4.0x10-5 torr) is maintained, and the temperature is raised to the melting temperature to form a eutectic molten metal. When DU and Zr were eutectic, the upper quartz tube assembly was lowered by melt casting and immersed in the molten metal. High-pressure argon gas was injected to pressurize the molten metal and it was charged into the quartz mold. After charging, the mold assembly was raised and cooled at room temperature to manufacture a U-10wt.%Zr annular fuel.

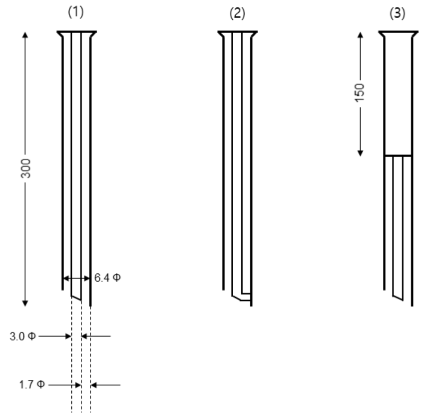

Fig. 1. Design of the quartz mold for annular fuel fabrication.

The injection casting process variables were set with reference to KAERI's existing research, and the specific process variables are shown in Table 1 [3]. In the initial process, injection was performed in an inert gas (Ar) environment, but many shrinkage cavities were found in the annular fuel manufactured under those conditions, and the soundness was judged to be poor (Figure 2(a)). Therefore, in the subsequent process, injection was performed in a high vacuum environment (4.0x10-5 torr).

TABLE 1. Density & porosity of the samples.

No.	Composition (wt.%)	Temperature (°C)	Mold design	Pressure (bar)	Room Condition
1	U-10Zr	1550	#1	3	Ar
2		1550	#1		10^{-5} torr
3		1550	#2		
4		1650	#1		
5		1550	#3		

The length of the annular fuel manufactured using quartz tube #1 was found to be 200~230 mm, and casting defects were observed at the top ~5 mm and the bottom ~20 mm. As a result of cutting the fuel horizontally and checking the cross section, eccentricity of the quartz column mold was observed at the bottom of the fuel. This is due to the movement of the internal pillar mold due to the flow of molten metal charged into the quartz tube during injection and the momentary strong pressure accompanying the injection. In particular, in the design (1) quartz tube, there was a problem that the quartz column mold attached to form the ring shape was long compared to the attachment area, so eccentricity easily occurred even with slight vibration or impact (Figure 2(b)). The annular fuel injected at 1650 °C did not show much difference from the annular fuel injected at 1550 °C, but there was deformation of the lower part of the fuel due to the high molten metal temperature.

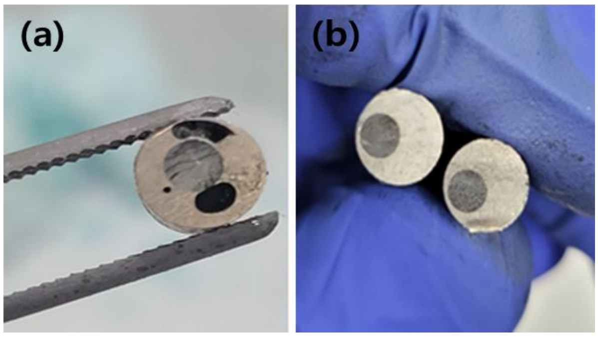

Fig. 2. Cross sections of the fabricated annular fuel. (a) Fabricated under Ar condition, (b) Fabricated using #1 mold.

In order to minimize eccentricity during injection casting, a support was added between the inner quartz column mold of quartz tube #1 and the quartz tube wall to protect it from pressure and impact. Injection casting was performed using quartz tube #2 under the same temperature and pressure conditions as before. An annular fuel manufactured through this showed a somewhat reduced eccentricity compared to the previously manufactured annular fuel, but the molten metal was not sufficiently charged into the quartz tube, and a fuel with a length shorter than the target specifications was manufactured.

To control the formation of casting defects, we attempted to minimize the vibration of the internal column mold by shortening the injection length to 150 mm like quartz tube #3. As a result of manufacturing a annular metal fuel by injection casting under the same conditions as before using quartz tube #3, the frequency of casting defects that occurred in the previous process was significantly reduced. Fuel deformation and eccentricity occurred at ~10 mm below the quartz tube due to high molten metal temperature. By cutting the area where eccentricity occurred at the bottom, a ~100 mm fuel was obtained. As a result of measuring the density of the manufactured ring-shaped fuel by cutting it into 10 mm lengths, it was confirmed that all specimens had more than 95% of the theoretical density.

Fig. 3. Fabricated annular fuel using mold #3.

3. Conclusions

This study manufactured and evaluated annular fuel with U-10wt.% Zr composition using injection casting. Based on the results of the existing injection casting research conducted at KAERI, process variables such as casting temperature, pressurization pressure, and atmosphere were set, and annular metal fuel were manufactured through various quartz tube mold designs. Annular fuel with an outer diameter of 6.40 mm, an inner diameter of 3.00 mm, and a length of more than 60 mm was manufactured, confirming the feasibility of manufacturing an annular fuel through injection casting. However, since surface cracks frequently occurred due to shrinkage due to cooling after injection, it is necessary to develop a method to suppress crack formation through control of process variables in the future.

Acknowledgments

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