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Development of a Gravity Casting System for Fabrication of Annular Metallic Fuel Slugs

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1. Introduction

Metallic fuels for sodium-cooled fast reactors (SFRs) have been widely investigated due to their high thermal conductivity, favorable neutronic characteristics, and compatibility with pyro-processing [1,2]. Conventional metallic fuel slugs are generally fabricated in a solid cylindrical form, with sodium bonding introduced between the fuel slug and cladding to enhance heat transfer. However, the sodium bonding process increases the complexity of fuel fabrication and handling. Recently, annular metallic fuel concepts with an axial central void have been proposed to improve thermal performance and accommodate fuel swelling during irradiation [3]. The annular geometry can reduce the heat conduction distance and provide additional space for inward radial swelling, while potentially eliminating the need for sodium bonding. Therefore, annular metallic fuel has the potential to simplify the fuel fabrication process while maintaining favorable thermal and mechanical performance.

Fabrication of annular metallic fuel slugs requires a casting process capable of forming both the outer geometry and a uniform internal cavity. In particular, stable filling of molten metal into a narrow annular mold is important to minimize casting defects such as incomplete filling, porosity, and dimensional nonuniformity. In this study, preliminary fabrication tests were conducted using a gravity casting method, which provides a relatively simple process configuration and utilizes the natural flow of molten metal. The preliminary tests demonstrated the feasibility of fabricating annular-shaped specimens and identified several factors requiring improvement, including melt delivery, filling stability, and mold configuration.

Based on the preliminary fabrication results, a new gravity casting system dedicated to the fabrication of annular metallic fuel slugs was designed. The system was configured to melt the material in an upper melting section and subsequently discharge the molten metal through an outlet into an annular casting mold located below by gravity. This study presents the results of the preliminary gravity casting tests and the design of the newly developed gravity casting system and mold, providing a basis for subsequent equipment fabrication and metallic fuel casting experiments.

2. Methods

Gravity casting was investigated as a simple fabrication method for annular metallic fuel slugs. In this process, the alloy is melted in a graphite crucible and introduced into an annular mold by gravity, as schematically illustrated in Fig. 1. Gravity casting provides a relatively simple process configuration and can achieve a high material yield by minimizing the amount of residual melt remaining in the crucible and transfer path.

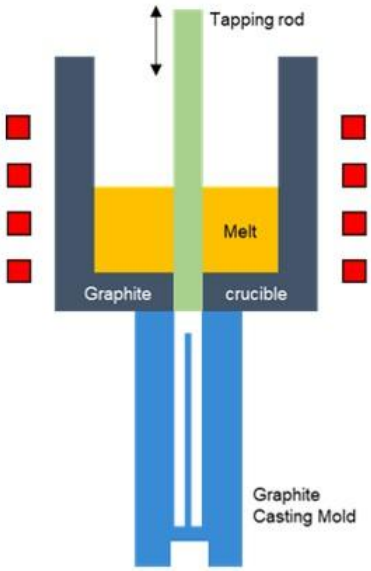


Fig. 1. Conceptual image of gravity casting

For the preliminary fabrication test, U-10Zr alloy was melted in a Y_2O_3-coated graphite crucible and cast into an annular graphite mold. The casting temperature was maintained at 1550 °C under an Ar flow rate of 10 mL/min. The feasibility of the gravity casting process was evaluated based on the macroscopic shape, cross-sectional morphology, and microstructure of the fabricated annular fuel slug.

3. Results and Discussion

As shown in Figs. 2 and 3, an annular U-10Zr fuel slug with a continuous central hole was successfully fabricated by gravity casting. The fabricated specimen

maintained a stable annular geometry and exhibited a relative density of approximately 94% of the theoretical density (TD). These results demonstrated that gravity-driven filling could be applied to the fabrication of annular metallic fuel slugs while maintaining a simple casting procedure and relatively high material utilization.



Fig. 2. Preliminary fabricated U-10Zr annular metallic fuel slug by gravity casting

However, localized defects were observed in the cross-section and microstructure of the cast specimen, as shown in Figs. 3 and 4. These defects were mainly associated with shrinkage during solidification, although the overall annular geometry was successfully maintained. The preliminary results therefore indicated that further improvement of melt delivery, mold filling, and solidification control is required to obtain more uniform and defect-free annular fuel slugs.



Fig. 3. Cross-sectional image of the preliminary fabricated U-10Zr annular metallic fuel slug

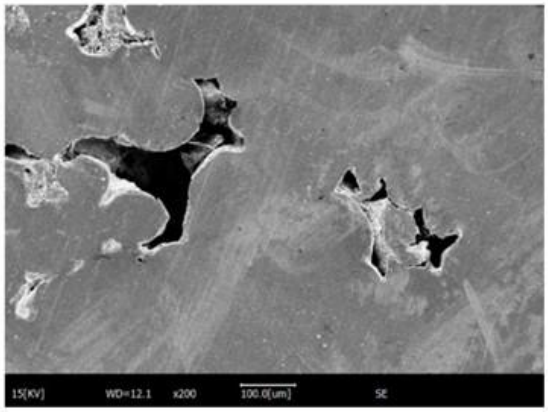


Fig. 4. Microstructure of the preliminary fabricated U-10Zr annular metallic fuel slug

Based on these preliminary casting results, a new gravity casting system was designed to provide more stable and reproducible fabrication conditions. As shown in Fig. 5, the newly designed system consists of an upper graphite melting crucible, a tapping rod for controlling melt discharge, and a lower graphite casting mold for forming the annular fuel geometry. The alloy is first melted under vacuum to minimize oxidation and contamination. After complete melting, the tapping rod is lifted to discharge the molten alloy into the lower casting mold by gravity. During melt flow, Ar gas pressure is applied to the upper chamber to assist the flow of the molten alloy and promote complete filling of the narrow annular mold cavity. This pressure-assisted gravity casting approach is expected to improve melt filling and reduce casting defects associated with incomplete filling and solidification. The newly designed equipment will subsequently be fabricated and used to optimize the casting conditions for annular metallic fuel slug fabrication.

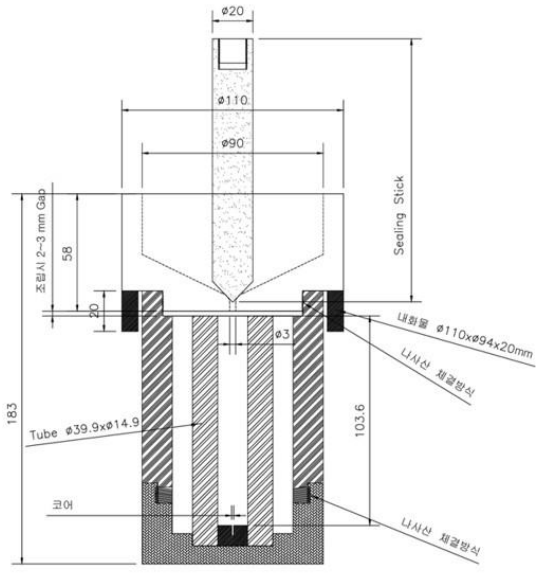


Fig. 5. Schematic drawing of the graphite crucible and mold for the gravity casting system

4. Conclusions

In this study, the feasibility of gravity casting for the fabrication of annular metallic fuel slugs was evaluated through preliminary U-10Zr casting experiments. A Y_2O_3-coated graphite crucible was used, and casting was conducted at 1550 °C under an Ar flow rate of 10 mL/min. The fabricated annular fuel slug maintained a stable geometry and achieved a relative density of approximately 94%TD, although localized shrinkage-related defects were observed. Based on these preliminary results, a new gravity casting system was designed to improve melt filling and process reproducibility. The proposed system incorporates vacuum melting, gravity-driven melt discharge using a tapping rod, and Ar gas pressurization during casting to promote complete filling of the narrow annular mold cavity. The newly designed system will be fabricated and further evaluated to optimize casting conditions and improve the quality of annular metallic fuel slugs.

ACKNOWLEDGEMENT

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