Hollow billet fabrication for hot extrusion of annular metallic fuel

Jung Won Lee, Ki Ho Kim, Sang-Gyu Park, Jeong Yong Park
KAERI, Next-Generation Fuel Technology Development Division,
Daedeok-daero 989 beon-gil 111, Yuseong-gu, Daejeon, Korea*
Corresponding author: jwlee3 @ kaeri.re.kr

1. Introduction

Metallic fuels have developed for innovative reactors and sodium cooled fast reactors (SFRs). Current research and development (R&D) activities on metallic fuels are focused on their potential use for actinide transmutation in SFRs. An innovative fuel design is to increase the burnup of metallic fuels, since higher discharge burnups equate to lower potential actinide losses during recycle. Promising innovations under considerations are: 1) lowering the fuel smeared density in order to accommodate the additional swelling expected as burnups increase, 2) utilizing an annular fuel geometry for better geometrical stability at low smeared densities, as well as the potential to eliminate the need for a sodium bond [1,2]. The annular metallic fuel design has been considered as a solution to relieve the fuel-cladding mechanical interaction (FCMI) caused by significant swelling of metallic fuels at high burnup, and it has been reported that the combination of annular fuel and lower plenum configuration is favorable to increase the average fuel burnup beyond 20%FIMA (Fissions per initial Metal Atom) without affecting fuel performance [3]. As an annular metallic fuel fabrication method, hot extrusion is promising. The most attractive advantage of extrusion method is to save the process waste by omitting the sodium process. 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 hot extrusion method [4]. In this study, as a first step to extrude metallic fuel, billet fabrication experiments were conducted by using copper (Cu) as a surrogate for uranium metal.

2. Methods and Results

2.1 Design of billet & annular fuel

The size of the billet and the fuel specimens for the production of the simulated annular fuels were determined. The annular shape having a diameter of 5 mm and a smear density of 75% was selected. For the production of this annular fuel, the billet shape was chosen a hollow cylinder type in outer diameter of 40 mm, and length of 50 mm, with a hollow diameter of 5 mm. In consideration of this billet dimensions, the graphite crucible was designed as shown in Figure 1.

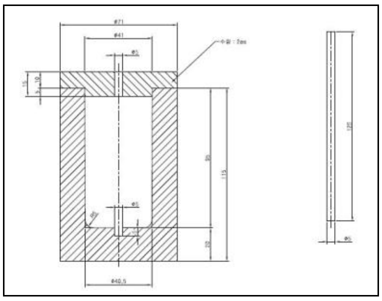

Fig. 1. Graphite crucible design for billet casting

2.2 Ingot preparation for billet casting

Figure 2 shows the general procedures to prepare billets for extrusion process. An ingot metal is prepared by casting or purchasing a raw material. In order to fabricate billets in this experiment, Cu was used as a surrogate for uranium metal, and Cu-2.5wt%Si alloy was used as a surrogate for uranium-zirconium alloy which was prepared by adding and melting 2.5wt% of silicon metal into copper ingot at 1300 ℃ under the vacuum (8×10^{-2} torr) atmosphere.

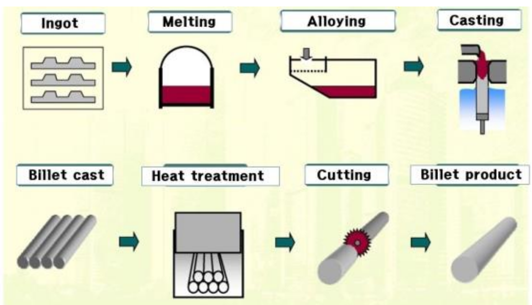

Fig. 2. General procedures for preparing billet

2.3 Billet casting for extrusion

Considering the physical properties of Cu, the target temperature for melting of ingot metal was decided as 1150 ℃ and the melt was held for 10 minutes for fully melting. (Fig. 3)

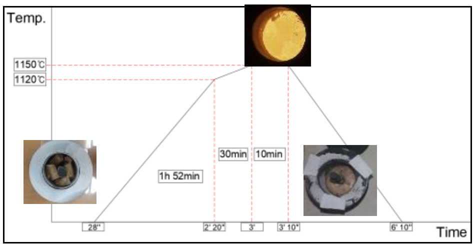

Fig. 3. Heating program for melting and casting billet

2.4 Evaluation of cast billet properties

In order to fabricate cast billets, melting and casting method was chosen by using a graphite crucible with a lid for the purpose of protecting severe oxidation during cooling. The diameter of billet is determined as 40 mm with a hollow of 5 mm diameter in the middle of billet to make annular fuel. Two types of billets were prepared, short one having 15 mm length, and long billet of 50 mm. Figure 4 shows the schematic diagram of billets.

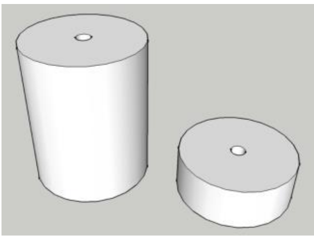

Fig. 4. Schematic diagram of hollow billets for extrusion

In order to control the length of billets, the amount of ingot loaded in the crucible was determined based on the density (8.94 g/cm^3) of Cu. To make a 50 mm long billet, 553 gr of ingot was loaded and melted. According to the heating program as shown in Figure 3, the ingot was fully melted at 1150 ℃ and cooled to the room temperature in the furnace. Figure 5 shows the cast billets produced by melting and casting.

(a) 50mm long billet (b) 15mm short billet
Fig. 5. Hollow cast billets for extrusion

The cast billets look black because of oxidation of the outer surface during cooling. In the case of long billet, it was almost impossible to manually remove the graphite rod in the middle of billet due to heavy friction between graphite rod and inner surface of the hollow. But the graphite rod was easily removed in the short billet, which means that it is desirable to reduce L(length)/ D(diameter) of billet for making the hollow billet. Figure 6 shows the cross section of the cast billet. Any defects such as pores or cavities were not observed and the immersion density of the cast billet is 8.8 g/cm^3, which is almost the same as the theoretical density.

(a) Cross section (b) magnified cross section
Fig. 6. Cross section of cast billets

Table 1. Density of cast billets.

	Spcimen1	Spcimen2	Spcimen3
Apparent Density (g/cm^3)	8.53	8.53	8.68
Immersion Density (g/cm^3)	8.83	8.86	8.88

On the basis of the results above, the cast billets with Cu-2.5wt%Si alloy for hot extrusion were successfully fabricated as shown in Figure 7.

Fig. 7. Hollow cast billets with Cu-2.5wt%Si for extrusion

3. Conclusions

KAERI has been developing the annular fuel fabrication technology by using hot extrusion method for the production of innovative metallic fuel. In this study, for the extrusion of metallic fuel, the hollow cast billet fabrication experiments were conducted by using Cu and Cu-2.5wt%Si alloy as surrogates for uranium metal and for uranium-zirconium alloy. The hollow cast billets were successfully fabricated by melting and casting process. But, the shorter the length(L) of billet is, the better the hollow billet is fabricated. There was not found any problems in fabricating the hollow cast billets for the hot extrusion of annular metallic fuel.

Acknowledgement

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

REFERENCES

[1] S. L. Hayes, "Advances in Metallic Fuels for High Burnup and Actinide Transmutationl", INL/CON-16-38752, 2016.
[2] Randall S. Fielding, "Co-Extrusion of Zr Lined U-Zr Alloy Characterization Report", INL/EXT-18-44550, 2018
[3] Yinbin Miao, "Fuel performance evaluation of annular metallic fuels for an advanced fast reactor concept", Nucl. Eng. Design, 352, 2019, 110157 1-9
[4] S. G. Park & J. Y. Park, "Correlation between billet microstructure & anisotropy of annular fuel fabricated by hot extrusion method", KNS Spring meeting, May 21-22, 2020, Jeju, Korea.