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Design and Manufacture of Reusable Graphite Molds for Metal Fuel Rod Manufacturing Process

Jeong Kyungchai+, Oh Seokjin, Kim Kihwan, Kook Seoungwoo, and Park Jeongyong

Korea Atomic Energy Research Institute, Daedeok-daro 989-111, Yuseoung-gu, Daejeon, 305-353, Korea
*Corresponding author: kcjeong@kaeri.re.kr

1. Introduction

In the case of a SFR using liquid Na metal as a coolant, various types of fission materials may be used as fuels, but oxide fuels and metal fuels are mostly used. In Korea, the development of Na-cooled fast reactor using such nuclear fuel is being carried out till the research stage for construction of the test reactor, and metal fuel is being adopted in the form of nuclear fuel charged here. It is based on loading metal fuel into the test reactor, and is conducting research to process it into metal fuel based on the raw material produced by pyro-processing policy of dry spent fuel.

Metal fuel is generally manufactured in the form of rod using a vacuum atmosphere in a high temperature injection casting furnace [1,2]. The composition of the raw material is considered to be a metal alloy containing an appropriate amount of RE materials such as Ce, Nd, Pr, and La component in U-10Zr composition [3].

In order to manufacture metal fuel in the form of rods in high temperature injection casting furnace, special molds are required. In most countries of the world, quartz tubes are processed and used. However, since quartz molds are produced in a form of wastes in case of using a multi-component RE constituents so that nearly cannot be reused after fuel rod manufacture. These factors can be a disadvantage for the economics and environment in spent fuel recycling process.

In this study, we designed and manufactured molds using graphite material with similar properties to the thermal properties of quartz tube. In particular, we tried to find out the possibility of reusability by making assembly-type graphite molds, fabricating them, and using them to manufacture fuel rods.

2. Metal Fuel Fabrication

The metal-type nuclear fuel fabrication process mixes metal raw materials such as U, Zr, and REs according to the characteristics of the reactor core, melts them in a hot melting furnace and is injected to casting molds using pressurizing gas [4].

The injection casting process melts metal components into the graphite crucible in a high-temperature induction furnace, and then enters them into the mold (quartz mold, in this study), cools them down to manufacture the metal fuel rod. And this metal fuel rods thus manufactured are used as metal fuels through proper quality control and inspection.

Metal fuel rods manufactured in this study were prepared by melting metal with U-10Zr-5RE components, charged into a graphite crucible in a vacuum atmosphere, heated to about 1500℃, and then homogenized by eddy current. When the molten metal was homogenized, an experiment was carried out to press-casting with Ar gas to inject the melt into the mold. After injection casting is completed, cool the mold by slowly lowering in furnace with Ar atmosphere.

And then, the mold is taken out from the injection casting furnace, and the fuel rod withdraw to analyze the fuel properties and manufacturing characteristics. Empty molds with fuel rods removed are prepared with specimens for chemical analysis of each component present therein and subjected to elemental analysis. The injection casting molding apparatus used in this study is shown briefly in the Fig. 1.

Fig. 1. Injection casting furnace system.

3. Graphite Material Properties

In addition to minimizing the loss rate of fuel materials when using quartz tube molds, this study aims to develop molds using graphite, paying attention to the properties of graphite materials used as molten alloy crucible materials in the metal fuel rod manufacturing process.

Generally, graphite materials have the following characteristics compared to metals or other ceramic materials [5];

- low heat resistance
- low friction coefficient and good self-lubrication
- high electric conductivity, heat transfer rate and low thermal expansion rate
- low wettability to molten metals
- high resistance to neutron irradiation

On the other hand, although the reactivity between graphite and uranium varies slightly depending on the reaction temperature, the reaction characteristics as a single species is not large. Graphite and uranium have been reported to penetrate up to about 50μm while forming uranium carbide(UC) at a reaction boundary at about 1150℃ for 200hrs [6].

Therefore, considering that the contact time between the graphite mold and the uranium compound is about 7-8 sec, the depth of uranium penetration into the graphite mold is expected to be negligible.

4. Graphite Mold Fabrication and Application

In this study, graphite was used to fabricate a tube-shaped graphite mold for the manufacture of metal fuel rod. The processing of the graphite tube was carried out through consultation with the industry, and the physical properties of the graphite material were processed in the form of tubes using graphite rods as shown in following table 1.

Table 1. Physical properties of graphite mold.

Physical Properties	단위	Standard Products
Bulk Density	g/㎤	1.80
Carbon Content	wt%	>99.9
Ash Content	ppm	200
Compression properties (surface direction, 5% deformation intensity)	MPa	140.2
Bending properties (thicknessdirection, rupture intensity)	MPa	80.0
Resistivity surface direction thickness direction	[illegible] cm	1,300
Average thermal conductivity values(50mm thick) in vacuum under standard pressure (Nitrogen)	W/m/K	100.0
Coefficient of thermal expansion	×10⁻⁶/K	5.0

In general, it is very difficult to fabricate a graphite tube having a thin thickness and precise straightness. The Fig. 2 shows the actual graphite molds fabricated in the form of assembly-type for this study. Here, the reason for the fabrication is to reuse of graphite molds used after fuel rod production.

Fig. 2. Assembly-type graphite molds.

By using the assembly-type graphite mold preliminary product prepared above, it was applied to the metal fuel rod manufacturing process. The metal fuel composition used in the fuel rod using the injection casting furnace was U-10Zr-5RE, and was melted at 1473℃. The inner surface of the mold was used as a mold after brushing with a Y_2O_3 slurry solution a day before making the fuel rod.

Fig. 3 shows the process of withdrawing the fuel rod after manufacturing the metal fuel rod using graphite mold with improved inner surface flatness. When the fuel rod was manufactured using the improved mold, it was not easy, but it was successful to separate the fuel rod from the graphite mold. Because of the assembly-type mold, the coating layer of the reaction protection layer was not completed in the cap part of the mold, so the fuel rod was not separated naturally.

Fig. 3. Metal fuel rod and disassembled graphite mold.

The surface of the fuel rod has a different gloss from the existing quartz mold. Further studies will be conducted to analyze the reaction phenomena through analysis of the fuel rod surface and to improve the internal coating method of the protection coating layer.

5. Conclusions

Graphite material was selected as a substitute material to reduce waste generation, which is a disadvantage of quartz mold, and the possibility of manufacturing graphite mold was investigated by using graphite material. As a result of prefabrication of fuel rods using graphite materials, it was found that the separation of fuel rods is not easy due to the poor workability of the inner surface. Due to the incompleteness of the slurry coating at the joint between the mold tube and the cap, the natural separation was not easy. The fabricated fuel rod surface also exhibits characteristics different from those made in conventional quartz molds. Research on improving the manufacturability of the graphite mold and improving the surface characteristics of the fuel rods will continue.

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