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Reaction Characteristics at Quartz Mold Inside in Metal Fuel Rod Fabrication and Preliminary Study for Alternate Mold Material Selection

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

As part of the research to recycle spent nuclear fuel from normal operation of domestic nuclear power plants (LWRs), a research on the concept of generating power using pyro-processing process development (dry process) and Na-cooled fast reactor is actively underway [1,2]. Because of the fuel materials produced through the pyro-processing process contain various types of radioactive nuclides, the reuse of them is also a source of concern in the United States and other advanced countries. Also the advantages of being able to recycle fissile radionuclides for contributing to nuclear non-proliferation.

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. The manufacture of metal fuel rod is common in the use of a metal fuel core based on uranium and zirconium. Since radioactive materials from spent fuel contain elements of various nuclear species after pyro-processing they are produced in the form of metal ingots, the fuel fabrication process development is underway to utilize them to manufacture metal fuel rod.

2. Metal fuel rod characteristics

The metal-type nuclear fuel fabrication process mixes metal raw materials containing different constituents into appropriate composition according to the characteristics of the reactor core, melts them in a hot melting furnace, and is manufactured from metal fuel rod using injection casting or gravity casting methods (see Fig.1) [3].

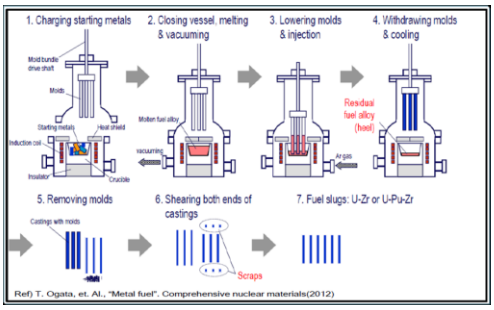

Fig. 1. Schematic flow diagram for injection casting.

Each fabrication method has its advantages and disadvantages, and in this study, a process of selecting injection casting method is developed to manufacture metal fuel rod. The injection casting process melts metal components into the graphite crucible in a high-temperature induction furnace, and then enters them into the mold (the quartz tube in this study), cools them down to manufacture the fuel rod as shown in Fig.2, and then metal fuel was manufactured after proper quality control.

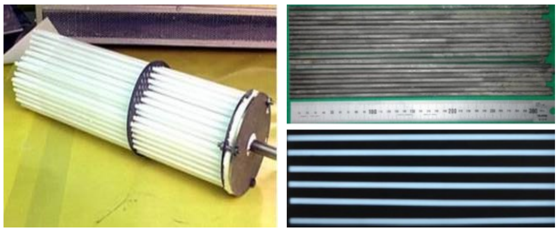

Fig. 2. Quartz molds bundle and fuel rods prepared from injection casting process.

In this process, the crucible for melting metal fuel and the mold for producing fuel rod are used almost only once. This is a major factor in reducing the economic feasibility of fuel fabrication and generating the amount of radioactive wastes. In particular, there are difficulties in waste disposal as well as loss of nuclear fuel materials, since the waste is generated in graphite crucible or quartz mold that occurs after the manufacture of the metal fuel rod. To overcome this, research is being carried out simultaneously on the improvement of the fuel rod manufacturing process or the development of alternative materials that can be able to alternating the use once.

3. Micro-adhesive force improvement of mold inner surface

As mentioned above, a high temperature injection casting furnace is used to melt the metal fuel constituents. After melting the raw material from the graphite crucible, the melt is inserted into the quartz tube mold, cooled down after follow-up, and the metal fuel rod, as shown in Fig. 2 above, is obtained. In this study, a layer of ceramic coating is applied to the inner surface of the quartz tube mold to protect reaction with the melt and quartz because the melting temperature of the metal melting is nearly 1500-1600°C.

In general, this ceramic coating layer brushed and dried using with a Y_2O_3 (or ZrO_2) slurry solution. However, the material properties of quartz mold make it difficult to adhere the slurry coating layer because they have very slippery surfaces [4].

To overcome these shortcomings, the inside of the quartz tube was sandblasted using Al_2O_3 powder to form roughness of the inner surface, thus attempting to improve the process of increasing adhesion of the coating layer [5]. To analysis the difference in adhesion force, a micro-adhesion measuring device called SAICAS is used to measure the micro-adhesion force of ceramic coating layer and is shown in Fig. 3.

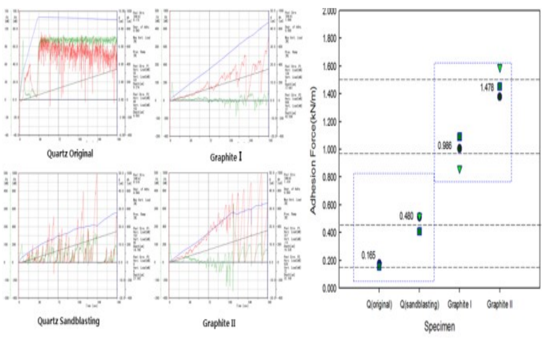

Fig. 3. Micro-adhesive force measurements of quartz and graphite specimen.

Comparing the micro-adhesion force of the sandblasted and the non-sandblasted specimens, the micro-adhesive force of the treated-specimens was three times stronger than before. This method could be employed as a way to improve the adhesion-performance of ceramic materials on the inner surface of quartz mold.

Meanwhile, the conditions of the coating layer before and after improving the roughness of the inner surface of the quartz mold are observed (Fig. 4.). Microscopic photographs after natural drying at room temperature for two days after brushing of ceramic coating solution on its surface showed much better application of coating layer after surface roughness improvement.

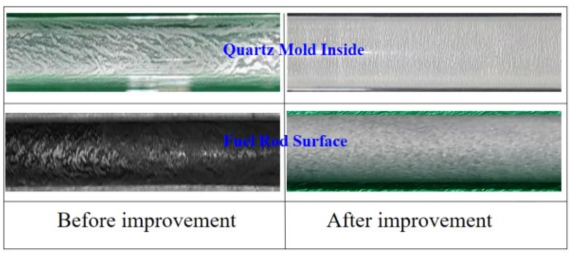

Fig. 4. Coating layers and rod surfaces before and after surface roughness improvement.

In addition, if you look above of Fig. 4, which observed the surface of the prepared fuel rod after manufacturing the metal fuel rod using a quartz mold made of this improved process, it can see that the surface of the metal fuel rod obtained when treating the inner surface of the quartz mold is much more metallic and smooth than that of used without treating the mold surface.

Therefore, it is thought that quality improvement can be achieved in the metal fuel rod manufacturing process by using the quartz mold having improved adhesion of t he reaction prevention layer by utilizing sandblasting m ethod in the fuel rod manufacturing process.

4. Reaction characteristics in metal fuel rod fabrication

In the process of manufacturing metal fuel rods worldwide, since quartz molds are used almost only once, a large amount of quartz mold wastes are generated after metal fuel rods are manufactured, and a small amount of nuclear fuel raw materials is mixed with these wastes. In order to minimize the amount of generation thereof, research is being conducted, but due to the reaction characteristics between the melt and the quartz mold, a certain amount of raw material is generated like waste.

Fig.5 shows the reaction characteristics of the Si component formed in the mold present on the surface of the metal fuel rod when the ceramic coating layer at the quartz mold is used and or not used. Even if the reaction prevention layer is used in metal fuel rod manufacturing, it is not possible to protect basically the Si component from penetrating into the fuel rod surface at the source, but it is important to minimize it.

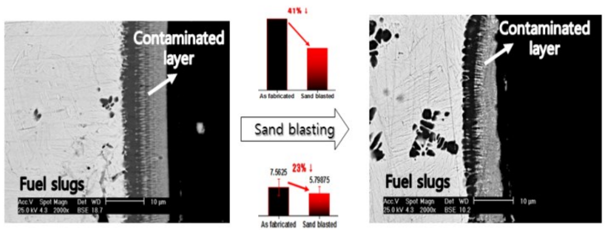

Fig. 5. Quartz inner surface and Si contaminated length (left ; without coating layer, right ; with coating layer).

Adhering-force improvement the inner surface of the quartz mold with the reaction protection layer of the ceramic material of Section 3 is also part of the study to minimize the penetration of Si components from the mold. If use this method, it seems to effect to some extent.

5. Alternative mold material survey

As mentioned earlier, quartz tubes are used as molds for the manufacture of metal fuel rods. They are used for almost only once, resulting in a considerable amount of waste and loss of fuel material. Therefore, in this study, the development of alternative material that can replace the quartz mold is in progress. Since metal fuel rod is manufactured at high temperature of 1600 ℃ and the chemical reactivity of metal melts is very high, it is possible to use ceramic type material rather than metal. As a result of preliminary research, graphite material is selected. Graphite is a material with high heat transfer characteristics, high heat resistance, low thermal expansion coefficient, and high resistance to neutron irradiation [6].

High purity graphite has low reactivity with uranium at high temperatures, and has been selected as an alternative mold material to replace quartz molds. The disadvantage is that it is difficult to fabricate into a mold, but the development of processing technology has solved the difficulty. Another advantage of graphite material is that the relative specific surface area of graphite material is much larger than that of quartz tube material, so the micro-adhesion force can be greatly increased when brushing ceramic coating layer.

As shown in Fig.3, the micro-adhesive force in the graphite specimen was analyzed to be about 9 times stronger than that of the quartz specimen. Also, since the specific surface area of the graphite mold is expected to be much larger than that of the quartz mold, the micro-adhesive force of the ceramic protection layer inside of graphite mold is expected also relatively strong. Thus, the study which the graphite mold is applied for replacement the quartz mold will continuously progressed in metal fuel rod fabrication.

6. Conclusions

In this study, the results of the study on the improvement of surface roughness of quartz mold and the reaction characteristics of the quartz mold and fuel melts in the fabrication of the metal fuel rod were briefly mentioned. Also, the material properties and the possibility of mold making as a substitute for quartz mold, which is currently used in the manufacture of metal fuel rod, were investigated. Here, the reason for replacing quartz with graphite is to minimize the fuel loss rate and to address the possibility of reuse.

REFERENCES

[1] K.Marsden, “Report on Development of Concepts for the Advanced Casting System in Support of the Deployment of a Remotely Operable Research Scale Fuel Fabrication Faculty for Metal Fuel”, INL/EXT-07-12469, (2007).

[2] D.E.Burkes, R.S.Fielding, D.L.Porter, C.Crawford, M.K.Meyer, “A US Perspective on Fast reactor Fuel Fabrication Technology and Experience Part I: Metal Fuel and Assembly Design”, J. Nucl. Mater., 389, 458-469 (2009).

[3] R.S. Fielding, J. Crapps, C. Unal, J.R. Kennedy, “Metallic Fuel Casting Development and Parameter Optimization”, INL/Con-12-26868 (2013).

[4] http://www.zypcoating.com, Y Aerosol brushable (Yttrium oxide).

[5] A.Rudawska, I.Danczak, M.Muller, and P.Valasek, “The Effect of Sandblasting on Surface Properties for Adhesion”, Int. J. Adhesion & Adhesives”, 70, 176-190 (2016).

[6] http://www.subtech.com, Graphite molds for continuous casting.