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Reaction Characteristics at Fuel Rod Surface Obtained from Metal Fuel Fabrication Process

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1. Introduction

Research is under way to minimize fuel loss in the metal fuel rod manufacture process, which is considered a very important issue in terms of recycling spent nuclear fuel [1, 2]. Generally, metal-fuel production is performed by selecting metal constituents having proper composition ratios according to the characteristics of the reactor core, melting them in a high-temperature melting furnace, injection casting and cooling them in a proper mold and fabricating them into fuel rods [3].

Quartz tubes are commonly used as mold to manufacture metal fuel rods, and to prevent reaction between metal melt and mold, an yttria (or zirconia) slurry solution is applied to the inner surface of the quartz tube by forming of suitable thickness protection layer to prevent reaction with the quartz tube. However, since the inner surface of the quartz tube is very slippery due to the nature of the glass, it is difficult to use a slurry solution here to form a protective layer.

The importance of proper equipment and sandblasting media selection to improve an adherence of the slurry coating layer were emphasized for this purpose[4], and the pre-survey results showed that sandblasting equipment, such as those shown in Fig. 1, was selected and the results for sandblasting studies have already been reported.

EQUIPMENT	ITEMS	SPEC.
DESIGN BASIS	OBJECTIVE METHOD LOADING BLASTING MEDIA MEDIA SIZE POWER BLASTING PRESSURE POWER CONSUMPTION REQUIRED AIR	SURFACE FINISHING SUCTION AIR TYPE COVER GRATING TYPE Al-Oxide #80 220V x 2Ø x 60Hz Max. 7.0kg/㎠ , general 5kg/㎠ FAN 0.40 ㎾ LIGHT 0.1㎾ 0.65 ㎥/min at 6kg/㎠ (3.7 ㎾ COMPRESSOR required
BLAST CABINET	OVERALL SIZE BLAST ROOM SIZE DOOR SIZE TOUCH-UP	800W x 950L x 1400H 600W x 450L x 1200H 350W x 350H x 1SET Ø150 RUBBER GLOVE
BLAST GUN	NOZZLE BORE DIA. NOZZLE MATERIAL AIR ORIFICE DIAMETER ABRASIVE EJECTION AIR CONSUMPTION BLAST GUN Q'TY	Ø6.4 BORON CARBIDE Ø3.2 65 kg/Hr 0.65 ㎥/min at 6kg/㎠ 1 SET
COVER GRATING	MATERIAL SIZE	PUNCHING PLATE 2.3t 600 x 450L x 1 SET
DUST COLLECTOR	TYPE CAPACITY FAN DRIVE POWER FILTER BAG SIZE SHAKING TYPE	FILTER BAG TYPE 180 CFM 0.40 ㎾ x 2P x 220V Ø125 x 450L x 6EA MANUAL LEVER TYPE

Fig.1. Sandblasting equipment and operation conditions.

In this study, the micro-adhesion forces of the coating layer were measured and analyzed after coating the yttria slurry solution using surface-modified quartz mold made by optimum sandblasting conditions. It was also intended to identify the reaction characteristics at the surface of fuel rod obtained after molten melt injection with the surface-modified quartz mold to the manufacture of metal fuel rod.

2. Experiments

The inner surface of a smooth quartz tube was treated by applying the sandblasting method, so that the irregularly defects on surface were forcibly formed. Micro-adhesion force was observed using a micro-adhesion force measuring instrument called "SAICAS" after brushing an yttria slurry solution over a quartz plates and graphite discs. Quartz tubes obtained after sandblasting were internally coated with an yttria slurry solution, dried with a mold rotor to have a uniform coating thickness, and then mounted in an injection casting furnace for the manufacture of a metal fuel rod.

In order to verify the reaction characteristics of the molten melt and the surface of the quartz tube at high temperature, elemental analysis was carried out using SEM on the fuel rod surface obtained after dismantling the mold.

3. Results and Discussions

3.1 Sandblasted-tube preparation conditions

Table 1 shows the results of measuring the surface roughness of the quartz specimen carried out in this study. The quartz plate is a specimen that was carried out in sandblasting under the aforementioned optimum sandblasting conditions. Analysis of surface roughness measurement results showed that for quartz plate specimen, the surface roughness changed according to the incident pressure and working time of the media, and in this study, sandblasting operation was optimal for 28 seconds at a pressure of 2.7 to 2.8 kg/cm2.

Table 1. Results of surface roughness measurements.

Items		Measurement		Remarks
quartz		Ra(㎛)	Rz(㎛)	
Press.	2.5 kg/cm2	5.337	27.669	- Made of fused quartz glass by GE - Maximum working temperature : 1200℃ - Wall thickness : 2.0 mm - Size : length x width : 30x30 mm
	2.5 kg/cm2	7.369	39.121	
	3.0 kg/cm2	7.404	40.859	
	3.0 kg/cm2	7.191	38.681	
	3.5 kg/cm2	6.903	36.928	
	3.5 kg/cm2	6.456	34.456	
Original plate		0.009	0.085	
quartz tube		Ra(㎛)	Rz(㎛)	
Time	20 sec	3.014	19.080	Quarts tube spec. 45cm(L)x5.6mm(D)
	30 sec	7.977	37.208	
	30 sec(r)	7.523	35.272	
	40 sec	2.719	15.515	

Therefore, quartz tubes, which are used for actual fuel rod manufacture, were also made using tubes treated with this working conditions.

3.2 Micro-adhesion force measurement

To measure micro-adhesion force, a method of cutting is used by tilting from the surface of thin layer to the surface (substrate), and in Korea, a micro-adhesion force measuring instrument called SAICAS is used. In addition to physical properties such as stripping strength and shear strength, it is known that the interfacial conditions of the dissimilar materials can be observed through the slope cutting surface of the thin layer, or the dispersion characteristics of the painted-layer, weather resistance, etc.

Fig. 2 outline the results of the micro-adhesion force measured in this study using quartz plates and graphite specimens. A slurry coating layer dried on a smooth specimen generally maintains a constant balance between the forces applied horizontally and vertically as shown at left side in the Fig. 2.

The results of these analyses are summarized in Table 2 from measuring the micro-adhesion force of each specimen. Three times micro-adhesion forces were measured and averaged per specimen, and the strength of their was shown in order of graphite, quartz sandblasting sample and quartz original specimen.

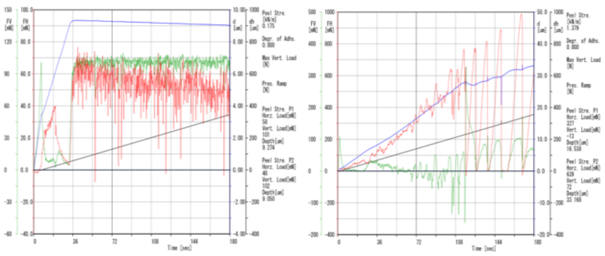

Fig.2. Micro-adhesion force of quartz and graphite specimen.

Table 2. Results of micro-adhesion force measurement on quartz plates and graphite specimen.

Sample	Measurement (kN/m)	Average (kN/m)	Remarks
Quartz (original)	0.175 0.165 0.155	0.165	<u>Measuring conditions</u> · depth/thick = 10 nm · blade width = 0.3 nm · expected shear angle = 45 deg. · horizontal velocity = 2000 nm/sec · vertical velocity = 100nm/sec
Quartz (sandblasting)	0.512 0.518 0.409	0.480	
Graphite I	1.006 0.862 1.090	0.986	
Graphite II	1.379 1.593 1.462	1.478	

3.3 Reaction characteristics at metal fuel rod surface

A metal fuel rod was manufactured using each mold to identify to leaching phenomena of Si element from the metal fuel rod surface prepared if or not there is an yttria coating layer inside the quartz tube mold. Test was performed on the U-10Zr-5RE alloy material. Fig. 3 shows that the reaction with Si in the contact face was progressed regardless of whether the coating layer was present or not.

By comparing the presence and absence of an yttria coating layer for reaction protection, we can see that the depth at which Si has been penetrated has changed with the long-direction position of the metal fuel rod manufactured. Initially, the penetration depth decreased with the increase of the metal fuel rod height, but after the minimum value was shown in the middle, it showed a tendency to increase again.

However, when coating layer was applied, Si penetration depth was minimized by the effect of reaction barrier in the contact with melt at the beginning of fuel rod manufacture, indicating a tendency to decrease with a slight increase in position

The application of surface-modified quartz tube molds is expected to reduce the tendency of Si melting and eluting to the metal fuel rod surface much less.

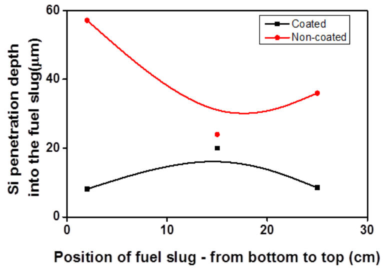

Fig. 3. Si penetration depths at fuel rod surface prepared by injection casting.

Meanwhile, the Si penetrating layer at the presence and loss of the yttria coating layer is observed and shown briefly in Fig. 4. After manufacture of fuel rod, the penetration depth of Si is observed from the SEM analysis on the fuel rod surface. Si penetration depth was significantly different depending on the loss of the yttria coating layer in the molds. This is expected to improve when the yttria coating is applied to the aforementioned surface-modified quartz molds.

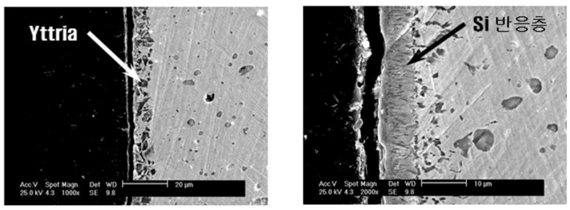

Fig. 4. Reaction characteristics at the fuel rod surface (left: coating layer holding part, right: coating layer loss part).

4. Conclusions

In this study, to strengthen micro-adhesion force of coating layer inner quartz mold used in metal fuel rod manufacturing process, surface modification was performed by sandblasting method to strengthen micro-adhesion force. The compared with the conventional method which is the no sandblasted-mold, the adhesion of the coating layer was thought to be more positive. Also, it was judged that Si's elution from the quartz mold surface was reduced compared to that of the conventional process, thus improving the process. Further research is likely to be needed to strengthen the adhesion of the coating layer.

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