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Wear Inspection for Fuel Channels in HANARO

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ABSTRACT

It has been observed that fuel assemblies have mechanical damage on some components due to the flow-induced vibration in the fuel channels. The major damage was the fretting-wear on the bottom end plates and spacer plates. Both the components are aluminum but cause the fretting-wear on the corresponding surfaces of the zirconium fuel channels. Also the bottom guide arms and top springs of the fuel are considered to be major parts that cause wear on the fuel channels. Therefore, the inspection of the inner surfaces of the fuel channels is required from a lifetime point of view. It is very difficult and time-consuming work to remove and install the fuel channels because of their inherent characteristics and the physical interference of other components in the reactor core. Thus we developed special tools for the inspection of the fuel channels by using an impression material without the removal of the reactor components. The impression material is a compound to replicate the damage of the fuel channels within a limited working time considering the hardening time as well as the radiation effect. The wear-inspection tool is a mechanical tool to press the impression compound against the inner walls of the fuel channels where the fuel components contact. The inspection tool has 36 molding cups that are operated in radial directions by turning the central rod with a fuel-handling tool from the pool top 12m above the reactor core. The same concept but a more compact design is applied to the cylindrical fuel channel.

The wear inspection was successfully accomplished for a few fuel channels. The results show visible wear marks on a hexagonal fuel channel at the positions corresponding to fuel components such as the bottom guide arms and top springs. The wear damage is slight, approximately 0.2mm depth, in comparison with the thickness (1.6mm) of the fuel channel. No visible wear mark has been found in the cylindrical flow tubes so far. The wear inspection is being continued for all the remaining fuel channels to get valuable results for estimation of the lifetime of the fuel channels. Also, we have another plan to inspect the deformation and/or wear of the spider pin of the fuel channel by using the impression material and proper tools. These inspections would also be helpful for the design improvement of the fuel assemblies.

1. INTRODUCTION

The HANARO in Korea is an open-tank-in-pool type reactor that has been being operated for 8 years since the initial criticality in May 1995. In the course of the visual inspection of the fuel assemblies, it has been observed that many of fuel assemblies had mechanical damage on some components due to the flow-induced vibration in the fuel channels called flow tubes. The hexagonal and cylindrical flow tubes are subjected to cooling water with a velocity of 7 m/sec. In the reactor, as cooling water is circulated, flow-induced vibration (FIV) occurs in the fuel channels. Due to this flow-induced vibration of the fuel assemblies, outer surfaces of some components of the fuel assemblies are likely to be bumped against inside walls of the fuel channels, whereby the fuel channels become worn.

The major damage of the fuel was the fretting-wear on the bottom end plates and spacer plates. Both the components are aluminum but may cause the fretting-wear on the corresponding surfaces of the zirconium flow tubes. Also the bottom guide arms (zirconium) and top springs (Inconel) of the fuel are considered to be major parts that cause the wear on the flow tubes. Therefore, the inspection of the inner surfaces of the fuel channels is required from a lifetime point of view.

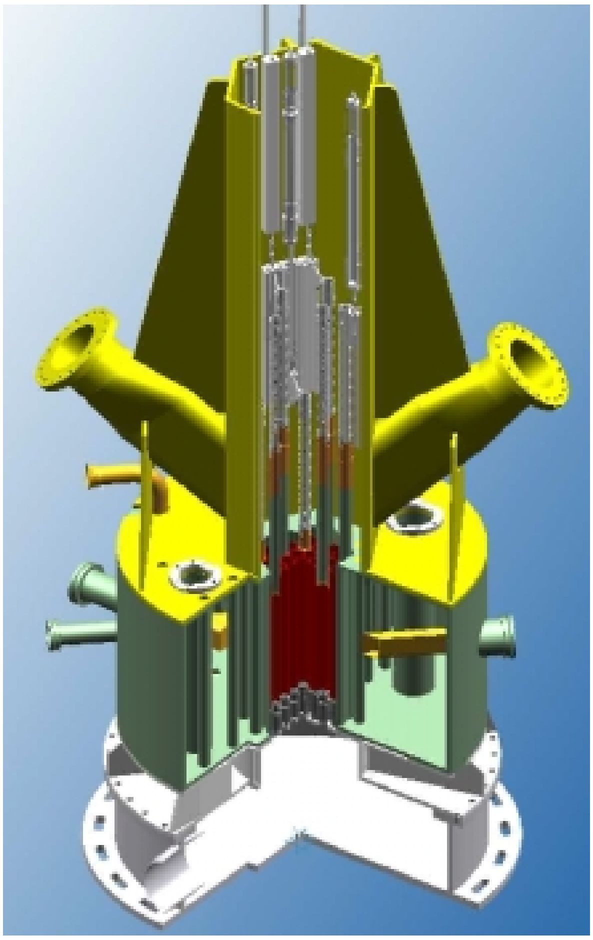


Figure 1. Reactor structure and internals of HANARO

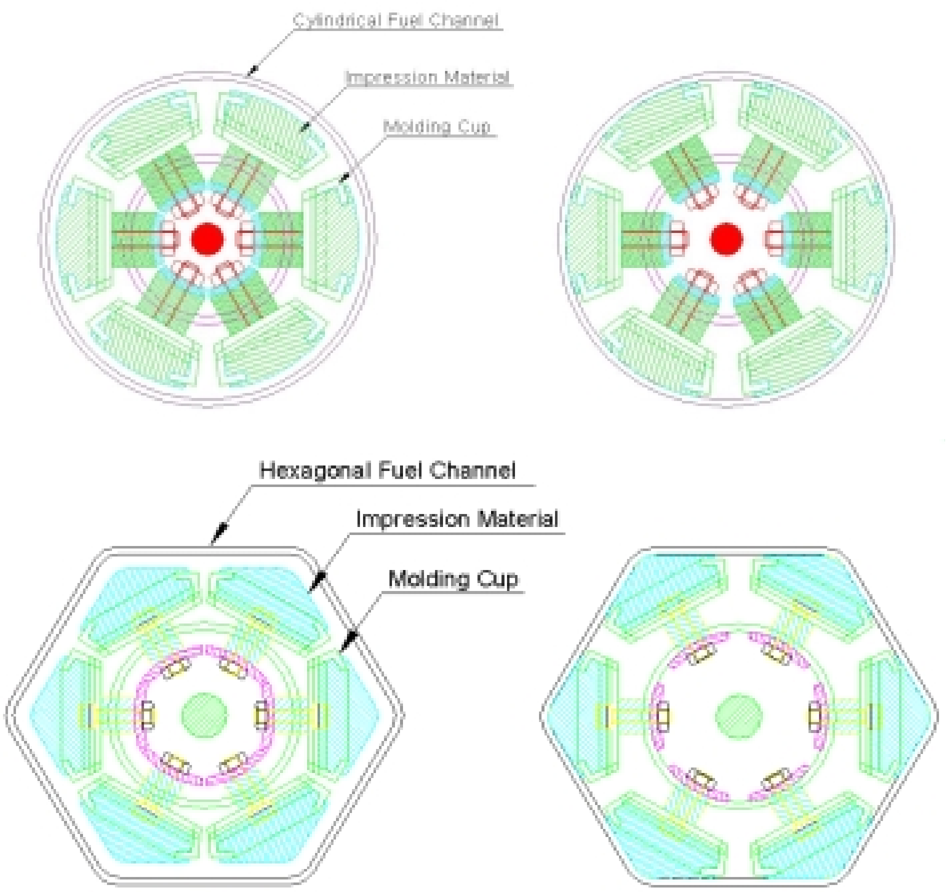
The reactor structure assembly consists of stainless steel inlet plenum and grid plate structures, zirconium alloy reflector vessel and flow tubes, and an aluminum chimney. The flow tubes (fuel channel) are secured to the grid plate. There are twenty-three hexagonal flow tubes and eight cylindrical ones.

Figure 1 shows the reactor structure and internals of HANARO and its physical interference with major components such as the control absorber units, the shut-off units and flow tubes. It is very difficult and time-consuming work to remove and reinstall the fuel channels(flow tubes) because of their inherent characteristics and the physical interference of other components in the reactor. Thus we developed special tools for the inspection of the fuel channels by using an impression material without the removal of the reactor components.

This paper describes the method and results of the fretting wear on the inside walls of the fuel channels.

2. DEVELOPMENT OF INSPECTION TOOL

We developed two kinds of remotely operable tools; one for hexagonal flow tubes and another for cylindrical flow tubes. The wear inspection tool is a mechanical tool to press the impression compound against the inner walls of the fuel channels where the fuel components contact. The inspection tool has 36 molding cups, 5 levels with 6 cups for each level, that are operated in radial directions by turning the central rod with a fuel-handling tool from the pool top 12m above the reactor core.



(a) Insertion of the inspection tool with impression material

(b) Contact of impression material with the inside wall

Figure 2. Concept of wear-inspection of fuel channel

Figure 2 shows the concept of operating mechanism for the hexagonal flow tube. The tool with the impression material attached as in the figure 2(a) is loaded and unloaded in the same method of fuel bundle. Figure 2(b) shows the status of the impression material pressed to the flow channel. The tool stays for a required time until the impression material is hardened. Thereafter, by measuring the size of the bumps formed on the impression materials, the worn-out status of the inner surface of the fuel channel can be easily grasped.

Figure 3 shows a hexagonal fuel channel. Figure 4 shows the wear inspection tools filled with the impression material in the molding cups for the hexagonal and cylindrical fuel channels.

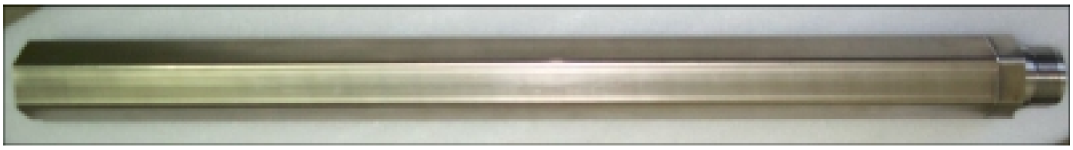


Figure 3. Hexagonal fuel channel

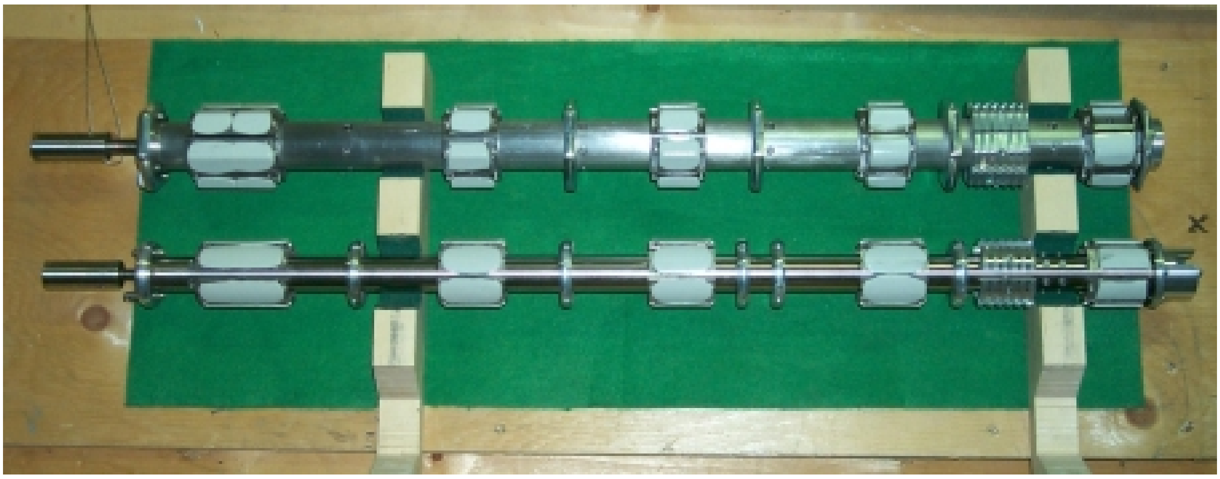


Figure 4. Wear inspection tools with the impression material
(Upper one for the hexagonal and another for the cylindrical fuel channels)

3. DEVELOPMENT OF IMPRESSION MATERIAL

The impression material is a compound to replicate the damage of the fuel channels within a limited working time considering the hardening time as well as the radiation effect. We developed, for our purpose, a proper impression compound from the commercial material basically composed of vinyl-poly-siloxane, SiO_2 and Al_20_3, which dentists generally use. The compound is capable of replicating generally 25-75 micro-meter in resolution with an elastic recovery less than 0.1%. In case of dental impressions, the compound is hardened in about 3-5 minutes around room temperature. The water temperature of 28-36 degrees C around core accelerates the hardening.

A proper mixing rate of the additional silica powder, the chemical retardant and the commercial material was decided through various tests to ensure good workability, proper density, proper hardening time as well as good as a good replication.

For the development of the compound and working procedures we considered the time for the compound attaching to the molding cups, tool handling time, the water temperature, self-deformations of the compound during tool handling, and radiation damage of the compound in the reactor core. We developed the impression material for our purpose and successfully accomplished the inspection of the wear marks for a few fuel channels. Following is a summary of the constraints for the impression material successfully developed.

- Handling time in air ---- more than 3 hours
- Temperature in air --- 20-25 degrees C
- Temperature in water --- 20-40 degrees C
- Handling time in pool water --- more than 2 hours
- Hardening time in pool water --- less than 5 hours
- Resolution of replication --- better than 75 micro-meter
- No damage of the impression material by radiation in the core for 24 hours
- No effect on the conductivity of the pool water
- No corrosion effect on the reactor components
- Self-deformation until locking of impression tool --- no contact allowed with inside walls of the flow tube

4. WEAR-INSPECTION FOR FUEL CHANNELS

In HANARO, the fuel assemblies can be remotely inserted into and removed from the fuel channels and rotated, using a handling mechanism. Here, the wear-inspection tool is inserted into the fuel channel and operated by the fuel handling tool. We finished the wear-inspection for two hexagonal

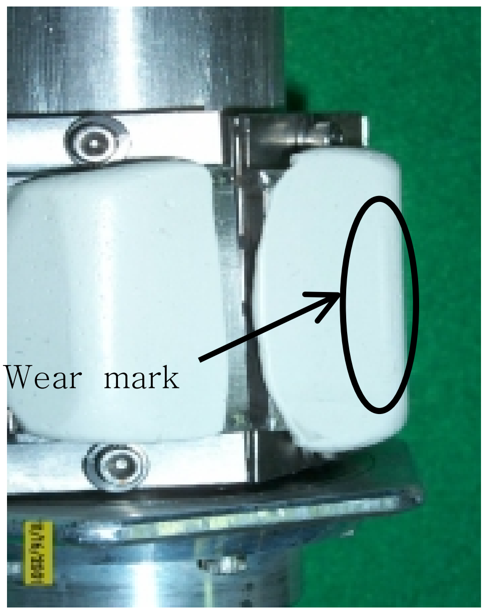


Figure 5. Wear mark by bottom guide
(0.2mm height X 20mm)

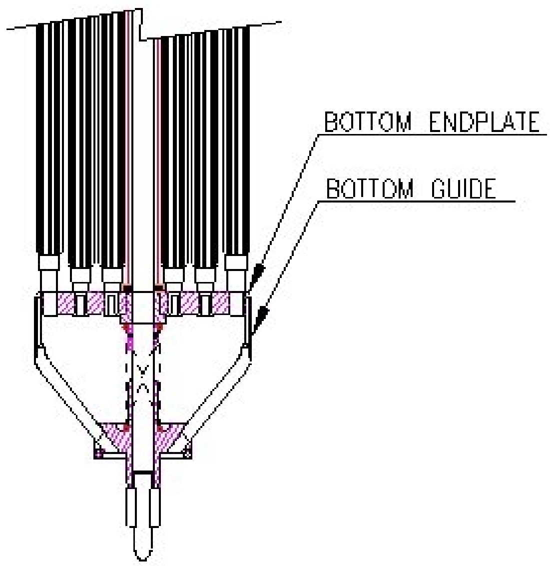


Figure 6. Lower part of fuel bundle

channels and one cylindrical channel that are judged to be in the group of the worst channels based on the statistics of the fuel inspection. The results show visible wear mark on one of the hexagonal flow tubes at the positions of the top guide and the bottom guide of the fuel assembly. Figure 5 shows a typical wear marks caused by the zirconium bottom guide of the fuel assembly shown in figure 6. But the wear damage is very slight, 0.2mm maximum depth measured by a precision dial gauge, in comparison with the thickness of the fuel channels (1.6mm). No visible wear mark has been found in the cylindrical flow tube so far. The wear inspection is being continued for all the remaining fuel channels to get valuable results for estimation of the lifetime of the fuel channels.

At the bottom of a flow tube, there are two pins to hold the fuel bundle against the rotational motion. The pins are to be worn out or deformed anyway. Therefore, we have another plan to mold the pins using the impression material and a proper tool which is to be developed.

5. CONCLUSIONS

It has been observed that fuel assemblies have mechanical damage on some components due to the flow-induced vibration in the fuel channels. The major damage was the fretting-wear on the bottom end plates and spacer plates. Both the components are aluminum but cause fretting-wear on the corresponding surfaces of the zirconium fuel channels. Also the bottom guide arms and top springs of the fuel are considered to be major parts that cause the wear on the fuel channels. Therefore, the inspection of the inner surfaces of the fuel channels is required from a lifetime point of view.

It is very difficult and time-consuming work to remove and install the fuel channels because of their inherent characteristics and the physical interference of other components in the reactor. Thus we developed special tools and impression material for the inspection of the fuel channels by using an impression material without the removal of the reactor components. The impression material is a compound to replicate the damage of the fuel channels within a limited working time considering the hardening time as well as the radiation effect.

The wear inspection was successfully accomplished for a few fuel channels. The result shows visible wear marks on a hexagonal fuel channel at the positions corresponding to fuel components such as the bottom guide arms and top springs. The wear damage is slight in comparison with the thickness of the fuel channel. No visible wear mark has been found in the cylindrical flow tubes so far.

The wear inspection is being continued for all the remaining fuel channels to get valuable results for estimation of the lifetime of the fuel channels. Also, we have another plan to inspect the deformation and/or wear of the pins at the fuel channel bottom by using the impression material and a proper tool. These inspections would also be helpful for the design improvement of the fuel assemblies if needed.