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# Research of Instrumentation Technologies for Material Irradiation at High Temperature

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As the reactors planned in the Gen-IV program will be operated at high temperature and under a high neutron flux, the requirements for irradiation of materials at high temperature are gradually increasing. Up to the present, the irradiation tests of the materials in HANARO have usually been performed at temperatures below 300℃, the temperature at which the RPV materials of commercial reactors are operated. To overcome the restrictions for the high-temperature use of Al thermal media of the existing standard capsule, a new capsule with double thermal media composed of two kinds of materials such as Al-Ti and Al-graphite was designed and fabricated as a more advanced capsule than a single thermal media capsule.

## 1. Introduction

Nuclear systems have evolved in accordance with concerns over energy resource availability, climate change, and energy security. Among them, Gen-IV nuclear systems are in the spotlight as future energy sources. These systems pursue sustainability, safety and cost-effectiveness, and proliferation risk reduction for future commercial development, which includes SCWRs (Super critical water reactors), SFRs (Sodium-cooled fast reactors), GFRs (Gas-cooled fast reactors), LFRs (Lead-cooled fast reactors), MSRs (Mol-ten salt reactors), VHTRs (Very high temperature reactors). KAERI (Korea Atomic Energy Research Institute) is taking part in the development of a VHTR and SFR. As characteristics of these reactors, their operating temperature and neutron fluence are higher than those of existing reactors. In HANARO, irradiation devices that require high-temperature and relatively low fluence were recently developed to meet the irradiation needs described above.

## 2. High-temperature Irradiation Capsule

The reactors planned in the Gen-IV program will operate at high temperature and flux as shown in Table 1. The outlet temperatures of VHTR and SFR are 1,000℃ and 550℃ respectively [1], which are much higher than the irradiation temperatures of material capsules tested in HANARO up to recently.

Table 1 Operation conditions of Gen-IV reactors

| Type | Temp (℃) | | Max. dose (dpa) | Pressure (MPa) | Coolant |
|---|---|---|---|---|---|
| | Inlet | Outlet | | | |
| PWR | 290 | 320 | 100 | 16 | Water |
| VHTR | 600 | 1,000 | 1~10 | 7 | He |
| SFR | 370 | 550 | 200 | 0.1 | Sodium |

Two types of capsules for high-temperature materials ware designed. One uses a single thermal media (specimen holder) made of Al, Ti, graphite, Mo, or Ni. The other uses a double thermal media composed of two kinds of materials, aluminum for the outer material and another material such as Al, Ti, graphite, Mo, or Ni for the inner material. The capsule with the single thermal media was designed to be irradiated at temperatures up to 550℃. The capsule with the double thermal media was designed for irradiation at temperatures up to 1,000℃. The first capsule with a double thermal media, the material of which consist of Al, Ti and graphite, was irradiated at temperatures up to 700℃.

## 3. Sealing at the Penetration Hole

Thermocouples and heaters, the materials of which are STS 310 and Inconel 600 were selected for use at temperatures up to 1150℃[2], instead of 304L, which has been used in the standard capsule for medium temperature irradiation. The instruments penetrate at the top end plug of the capsule and are sealed by brazing for water resistance. Brazing is a manual task in which a welder applies heat to melt a filler material. Therefore, the experience and technique of the welder are important for proper capsule brazing.

The instruments in an Inconel 600 sheath were broken during brazing and the filler material did not stick well to the base material. Among the many material capsules fabricated until now, the sheath material of the instruments is the first to break. Fig. 1 shows a normal and broken surface after brazing.

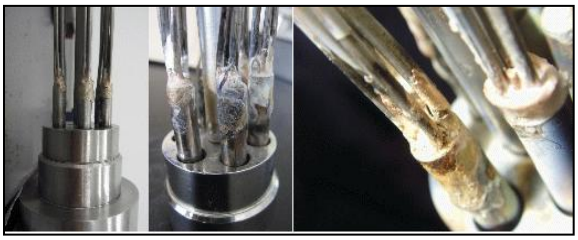

Fig. 1. Intact and damaged surfaces after brazing

The temperature of the brazing flame used in the standard capsule was higher than 1,427℃. This is contrary to the principle of brazing, as the temperature is higher than the melting point of the base material, STS 304L, of a standard capsule. The flame can be maintained at lower than 1,300℃ in the torch using butane gas.

STS 310 material was finally selected because Inconel 600 material is easy to break due to an increase in brittleness at high temperatures. The results of the brazing test for the Inconel and STS 310 materials are shown in Figs. 2 and 3. The integrities of the instruments housed in an STS 310 material are maintained even when twisted up to 720°. However, the instruments housed in an Inconel sheath were damaged during brazing with a 480° twist. Therefore, the Inconel material is inappropriate for use in high-temperature instruments. In conclusion, STS 310 material was chosen for use with high-temperature instruments.

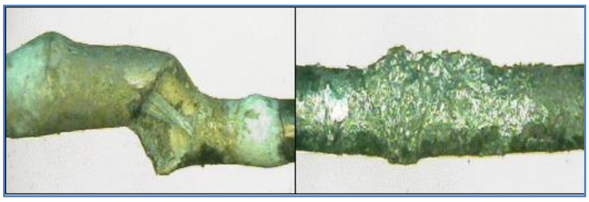

Fig. 2. Brazing after a twist(Inconel/STS310)

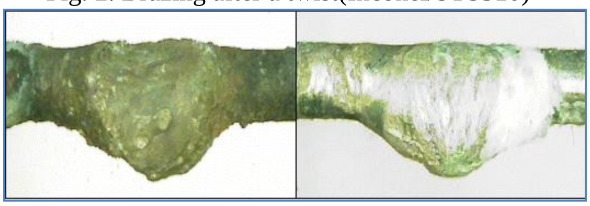

Fig. 3. Status after flaming heating without twist (Inconel/STS310)

## 3. Fluence Monitor for High-temperature

To measure the neutron flux at high temperature, a quartz or STS tube instead of an Al tube was used as the outer capsule containing the Fe, Ni, Ti material. Thus, the container will not melt as it will be used at temperatures below 1,000℃. Stainless steel is more likely to be contaminated with radiation than quartz material. For this reason, a quartz material was first used for the F/M container in HANARO. The quartz material must be heated to a high temperature to make a container with the help of skilled glass craftsmen. In addition, the quartz container should be broken in order to remove the specimen after irradiation. In the future, Zircaloy material will be used to replace the quartz container. Fig. 4 shows the conceptual shape of a high-temperature F/M.

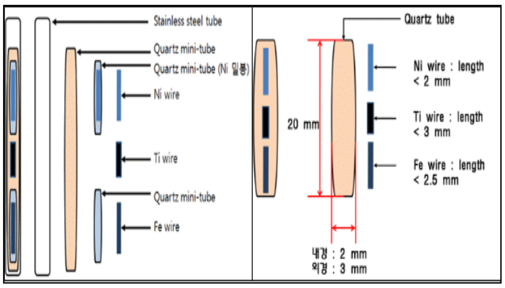


Fig. 4. High-temperature F/M

## 4. Conclusions

In accordance with the development plan of future nuclear systems in Korea, which are to be operated at high temperatures, a capsule suitable for irradiation testing at high temperatures was developed to overcome restrictions in use of aluminum at high temperature. In addition, a new capsule with a double-layered thermal media structure, the outer section of which is aluminum and the inner section is Ti or graphite, was fabricated. High-temperature instruments such as a thermocouple and heater were used in the new capsule. Also, the technology for the brazing of instruments at very high temperature was developed.

## Acknowledgements

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## REFERENCES

1. J.Y. Park, "Possibility of Fusion Applications of Current Materials R&D for GEN-IV Nuclear Energy System in KAERI", Korea-Japan Blanket Workshop (2009).
2. Homepage of Thermocoax Company, "http://thermocoax.com"