Development of High Temperature Irradiation Technologies

Man Soon Cho*, Kyue Taek Shim, Kee Nam Choo, Chul Yong Lee,
Bong Goo Kim, Young Hwan Kang, In Cheol Lim

Korea Atomic Energy Research Institute
1045 Daedeok-daero, Yuseong-gu, Daejeon, 305-600, The Republic of Korea
* *mscho2@kaeri.re.kr, Tel : +82-42-868-8431, Fax : +82-42-863-6521*

As VHTR and SFR projects are being carried ahead as a part of Gen-IV program presently in Korea, the requirements for irradiation of materials at high temperatures are recently being gradually increased. To meet these requirements, a new capsule with double layered thermal media composed of two kinds of materials such as Al-Ti and Al-graphite was designed and fabricated so that it would be tested at higher temperature than the single thermal media capsule. In this high temperature irradiation capsule, the technologies necessary for brazing of instrumentations at very high temperature should be developed.

1. Introduction

The reactors planned in the Gen-IV program will be operated at a 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.

The capsule for high-temperature materials was designed as a capsule with double layered thermal media, in which the outer one is aluminum and the inner contains material such as Ti, Mo, Fe, Zr, Gr. This capsule takes aim at irradiation at temperatures up to 1,000℃.

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

2. High Temperature Irradiation Capsule

A new capsule was fabricated for irradiation at temperature higher than 700℃. Ti and Gr were selected as materials for the thermal media in this capsule. Ti is lower in density and price when compared with other materials such as Zr, Nb, Mo etc., but the absorption cross-section of thermal neutron is relatively high. Graphite was also selected as a candidate material because the mechanical properties are excellent at high temperature and so used as the in-core material in VHTR [2]. Fig. 1 shows a double layered thermal media which are composed of Al/Gr or Al/Ti. The gap between the holder and specimen is 0.1mm, and between the inner and outer thermal media is 0.15mm, between the outer thermal media and outer tube the gap become 0.16~0.36mm, which was designed effectively to control the temperature of each stage. All gaps were filled with He gas of 101kPa.

Fig 1. Double layered thermal media(Al/Gr or Ti)

The appearance of the capsule is the same as shown in Fig. 2. The rod tip of the bottom guide tube was assembled with a receptacle in the reactor core, and the protection and guide tubes play the role of a guide for various signal lines such as the thermocouples, micro-heaters and helium supply tubes. The main body is a major part of the capsule in which specimens, measuring devices and various components were installed, and it includes an external tube of cylindrical shell with 60 mm in external diameter, 2.0 mm in thickness and 870 mm in length.

Fig. 2. Appearance of material capsule

3. Instrumentations and Brazing Technology

Thermocouples and heaters of which the sheath materials are STS 310 and Inconel 600 were selected for use at temperature up to 1150℃ instead of 304L which has been used to the standard capsule for medium temperature irradiation. The characteristics of the instrumentations for the standard and high temperature capsules are listed in the Table 2.

Table 2. Characteristics of instrumentations

	Standard capsule	High temperature capsule
Irradiation temperature	~400℃	700~1,000℃
Thermocouple		
• manufacturer	Thermocoax	Thermocoax
•sheath	STS 304L	Inconel 600/STS 310
• working T	700℃	1,150℃
Heater		
• manufacturer	Thermocoax	Thermocoax
• sheath	STS 304L	Inconel 600/STS 310
• working T	600℃	1,150℃

The instrumentations are penetrated at the top end plug of capsule and sealed by brazing. The brazing is a manual work which a welder applies heat and melts the filler material. Therefore, the experience and sensitivity of the welder are important in the brazing work of capsule.

The instrumentations with Inconel 600 sheath were broken during brazing and the filler material was not stuck well to the base material. The breakage of the sheath material of the instrumentations was occurred first among many material capsules fabricated until now. The Fig. 3 shows the normal and broken surface after brazing.

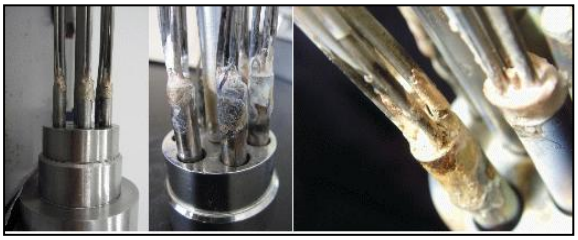

Fig. 3. Intact and damaged surface after brazing

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

The material of STS 310 was finally selected because Inconel 600 material is easy to break by an increase in brittleness at high temperature. The results of brazing test for STS 304L, Inconel and STS 310 materials are shown in Fig. 4. The integrities of the instrumentations of which the sheath material is STS 304L or STS 310 are maintained even if they are twisted up to 720°. However, the instrumentations with Inconel sheath were damaged during brazing in a twist of 480°. Therefore, Inconel material is inappropriate for use as high temperature instrumentations. In conclusion, the high temperature instrumentations were decided to use STS 310 material.

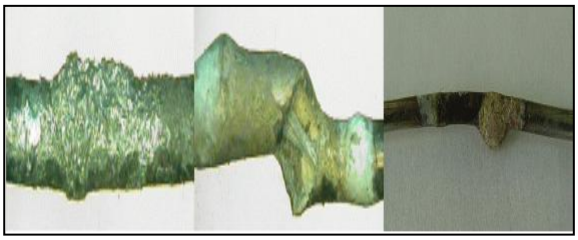

Fig. 4. Brazing after a twist
(STS304L/Inconel/STS310)

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 test at high temperatures was developed to overcome a restriction in use of aluminum at high temperature. The new capsule with the thermal media of double layered structure, of which the outer is of aluminum and the inner Ti or graphite, was fabricated. The high temperature instrumentations such as thermocouple and heater were reflected in the new capsule. In this capsule, the high temperature instrumentations such as thermocouple and heater were reflected. And the technology for brazing of the instrumentations at very high temperature was developed.

Acknowledgements

This work was supported by the Nuclear Research & Development Program of the National Research Foundation of Korea (NRF) grant funded by the Korean government (MEST).

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. W.K. Choi et al., “Nuclear Graphites (II) : Mechanical Properties,” Carbon Letters, Vol. II, No 1. 41-47 (2010)