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An Analysis of Safety and Integrity for the Thermal Media of a Capsule for High-Temperature in HANARO

M.S. Cho*, K.N. Choo, Y. T. Shin, J.M. Sohn, S. J. Park, Y.H. Kang and Y.K.Kim
KAERI, 150 Dukjin-dong, Yuseong-gu, Daejeon, Korea 305-353
**Corresponding author : mscho2@kaeri.re.kr*

1. Introduction

A capsule for the performance test of thermal media such as Fe, Zr, Ti, Mo, etc. was designed, fabricated, and tested in the HANARO out-pile test facility. During the thermal performance test, some heaters of the capsule were broken when measuring the temperatures at a low vacuum pressure. In this report, an attempt is made to find some causes for the heater breakage and their relations to the heater loss occurring often during the real irradiation test. The capsule was dismantled, and the structural integrity of the thermal media was investigated to review the appropriateness of the candidate materials chosen as the thermal media for high temperature.

2. Design and fabrication

Based on the previous technical examination and the performance test [1], a capsule for an out-pile test was finally designed and fabricated. The shape of the capsule is shown in Fig. 1. The external tube was made of STS316L with an outer and inner diameter of 56 and 52 mm, and the protection tube was made of STS304 with a diameter of 42.7 mm for utilization of the existing OR clamp. The specimens were the modified RPV steel of 9Mo-1Cr RPV and 40 pieces of Charpy ones. The irradiation temperatures of the specimens were 350~400℃. The target of the irradiation was 2.1×10^{19} n/cm^2 (E>1.0 MeV) at the OR5 hole.

Fig. 1 The capsule for an out-pile test

The capsule was composed of the thermal media of five stages with a separated thermal medium, the specimens, and an electric heater at each stage. The thermal medium had 4-holes to contain the specimens of STS 304 material with a dimension of 10x10x100mmL, as shown in Fig. 2. The various thermal media of Al, Fe, Zr, Ti, and Mo material were used for an irradiation at a rather high temperature. These materials are the candidates to be used as substitutes for the Al thermal media for an irradiation of high temperature materials in the future. The length of the main body was 813mm, and the total length including the main body and the protection body was 4934mm.

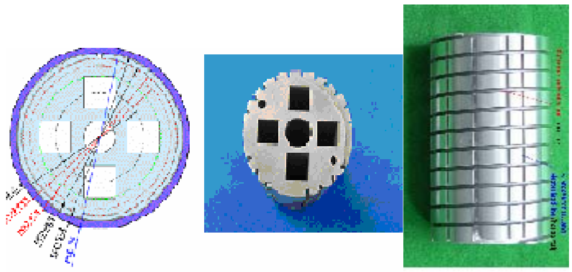

Fig. 2 Thermal media

3. The thermal performance test

The thermal performance test was undertaken at the heater power of 1800 and 2850W in the He environment of 760 and 100 torr. To measure the maximum temperatures of the specimens to be attained by using the various thermal media, the maximum powers of the heaters were first measured. The maximum temperatures were measured at 90~95 % powers of the heaters to prevent them from breaking.

The temperature of the specimens in the Fe thermal medium of the 2nd stage reached 400 °C at a 760 torr, and 593°C at a 100 torr. The temperatures were high in the order of Fe, Ti, Mo, Zr, and Al. The temperatures were inversely proportional to the value of the thermal conductance of the material. The temperature at the Fe thermal medium was the highest because the gap of 1 mm was the biggest while the gaps were 0.3 mm at other thermal media.

The maximum temperatures were measured with 90~95% heater power at the vacuum pressure of 36 torr. The maximum temperature reached 669°C at the 2nd stage with the Fe thermal medium.

Al, Fe, Zr, Ti, and Mo were used as the thermal media from the 1st stage to the 5th stage, respectively [1]. The temperatures of the specimens were measured at the vacuum pressures of 760, 100, and 36 torr. While measuring the temperatures at 36 torr, the heaters of the second to fifth stages were broken. It occurred 2 minutes after changing the internal pressure to 36 torr. The temperature of the specimen reached 669℃ which is the highest at the 2nd thermal media of Fe.

The heaters and thermal media damaged from the breakage of the heaters are shown in Fig. 3. The relation between the temperatures and the heater powers at the instant of the heater breakage are shown in the Fig. 3. To find where the breakage started, the graph for the temperatures and the time is shown there. The heater at the 1st stage was not broken until the end, while those at the 2~5 stages were all broken. As shown in the Fig. 4, the breakage of the heaters started from the 3rd stage using Zr material as a thermal medium, and next in order of the 4th, 5th and 3rd stages. The 4th heater was broken after 4 seconds, the 5th after 7 seconds, and the 2nd after 43 seconds from the breakage of the 3rd stage heater [2].

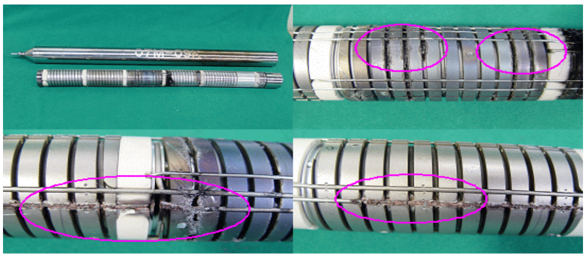

Fig 3. The damage of the heaters and thermal media

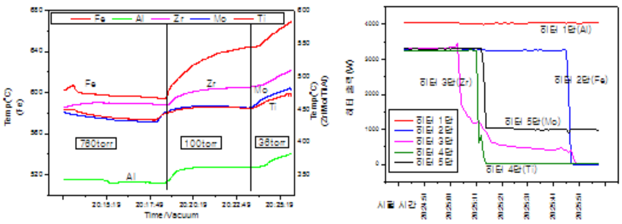

Fig 4. The temperatures and the powers at the instant of breakage

4. An Evaluation of the Themal Media

The contents of the damage and the corrosion of the thermal media due to an over-power of the heater are shown in the Table 1.

Table 1 The damages and corrosion of the thermal media

Thermal Media	Damage	Corrosion	Conducti-vity (W/mK)	Absorption cross-section
Al	normal	Clean	203.5	0.22
Fe	damage	Corrosion at room temp.	80.2	2.56
Zr	damage	Corrosion	22.7	0.18
Ti	damage	Weak corrosion	21.9	6.1
Mo	damage	Clean	138	2.6

This capsule was tested to investigate the appropriateness of Fe, Zr, Ti, and Mo materials as well as Al as the thermal media [3] at a rather high temperature. The breakage of the heater is believed to result from an over-power of the heater. However, the properties for heat transfer and electrical conductivity should be reviewed more. A high electrical power was supplied to the heater at the instant of the heater breakage, and so the thermal media were deformed and rusted due to the electrical sparks and high temperature. The thermal media at the 3rd stage were overheated, and nearly melted, and rusted so much that the surface was discolored black. Those of the 2nd stage were rusted easily; Fe was weak in corrosion and was discolored black in the upper and lower parts. Those of the 4th stage were rusted a little, and the 1st and 5th thermal media were maintained clean without rust. Material of Fe has a weakness for corrosion, and Ti has a very high neutron absorption cross-section. In this out-pile test, the breakage of the heater started at Zr, and the Zr thermal media was rusted a lot at the location that the heater line was melted. However, Zr is a recommended material, from a view point of the reactor operation, since the neutron absorption cross-section is very low. The use of Zr material will be reviewed once more in the next capsule irradiation test.

6. Conclusions

To investigate the appropriateness of materials to be used as thermal media in a rather high temperature, an irradiation capsule for testing at the out-core facility was designed, fabricated, and performance tested. The thermal performances test for Fe, Zr, Ti, and Mo materials, which will be used as the thermal media of the high temperature irradiation capsule, were undertaken. It was ascertained that the temperature of the specimens can be raised up to 700°C if Fe, Zr, Ti, and Mo are used instead of Al. In the capsule to be fabricated later for a test of the appropriateness of thermal media at a high temperature, the thermal media will be made in a double structure in which the materials for high temperature at the inner region and Al at the outer region will be used as the thermal media. Mo and Zr are recommended as candidate materials for thermal media at a rather high temperature, and graphite is under review as another alternative.

Acknowledgements

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