Irradiation Test of High Temperature Irradiation Capsule (15M-03K) up to 1000℃ in HANARO

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1. Introduction

As the future nuclear systems will be operated at high temperature and high neutron flux, the requirements for irradiation of materials at high temperature are gradually increasing. Up to the present, most of the irradiation tests of the materials in HANARO have usually been performed at temperatures below 300℃, at which the reactor materials of nuclear power plants are operated. And several materials for the future nuclear systems have been irradiated at around 500℃ [1,2].

To overcome the restrictions for the high-temperature use of Al thermal media (660℃ melting temperature) of the existing standard capsule, a new capsule with double thermal media composed of two kinds of materials, Al-Ti and Al-graphite, was designed and fabricated as a more advanced capsule than a single thermal media capsule. The irradiation temperatures of the capsule specimens were in the range of 700-900℃ [3].

To develop a very high temperature irradiation technology up to 1,000℃, a new capsule (15M-03K) with double thermal media of Ti and Fe materials was designed and tested in HANARO.

2. Design of Capsule

A 15M-03K capsule, as shown in Fig. 1, was designed for irradiation tests up to 1,000℃ in HANARO. Ti and Fe were selected as materials for the thermal media in this capsule. Figure 2 shows a schematic view of the capsule. It has a double-layered structure, the outer portion of which is made of Fe, and the inner portion is made of Ti. The gap between the holder and specimen is 0.1 mm, while that between the inner and outer thermal media is 0.2 mm, and the gap between the outer thermal media and outer tube is 0.26-0.29 mm, which was designed to effectively control the temperature of each stage.

The capsule is composed of only one stage with specimens at the center position to investigate the soundness of the instruments and the inner parts during the irradiation at high temperature. One electric heater was installed around the outer thermal media and 4 thermocouples were installed around the specimens to measure temperatures during irradiation tests. The thermal media has 4 holes to contain the specimens of STS 304/STS 316 materials with dimensions of 10x10x100 and 10x15x100 mm, as shown in Fig. 2.

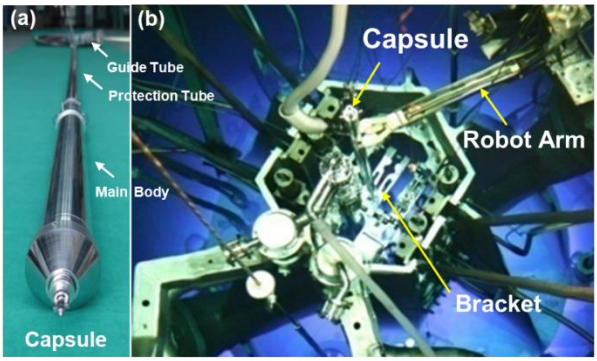

Fig. 1. HANARO irradiation capsule: (a) Irradiation capsule and (b) a capsule system installed in the reactor core.

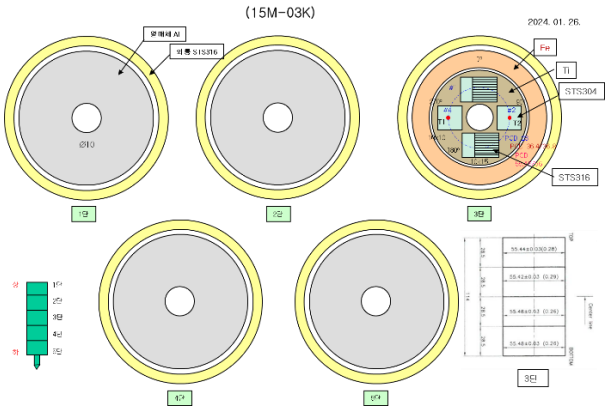

Fig. 2. Schematic view of double thermal media capsule

3. Irradiation Test in HANARO

The 15M-03K capsule was irradiated two times in HANARO and will be irradiated up to the 109 cycle. After the first irradiation test in 2018, the following test delayed until this year due to an unstable reactor operation.

The first irradiation test of the capsule was performed in the CT hole of the reactor at 30 MW thermal power and ended by an unexpected reactor shutdown during the irradiation in 2018, as shown in Fig. 3. The highest temperature of the specimen was 791℃.

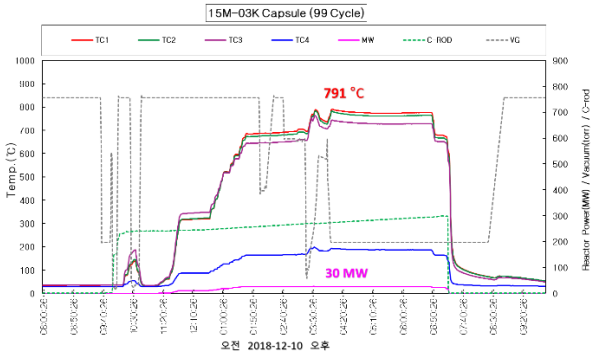

Fig. 3. Temperature variation of specimens during the first irradiation test of the 15M-03K capsule (Cycle No. 99).

The second irradiation test of the capsule was performed in the CT hole of the reactor at 27 MW thermal power in 2024, as shown in Fig. 4. The temperature of the specimen (T/C 1) reached 1,000℃ by decreasing the He gas pressure in the capsule from 1 atm (760 torr) to 35 torr and then decreased instantly by inserting He gas up to 1 atm into the capsule due to an unexpected decrease of the temperature of the specimen, and was maintained in the range of 720~760℃.

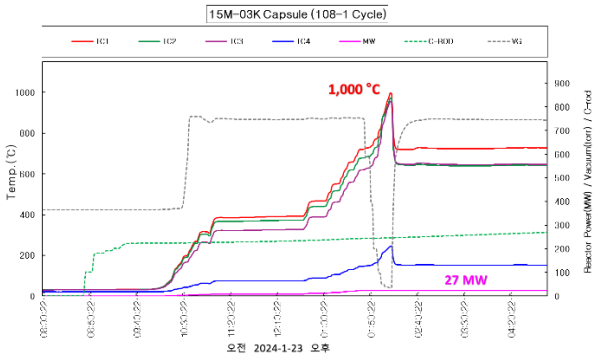

Fig. 4. Temperature variation of specimens during the second irradiation test of the 15M-03K capsule (Cycle No. 108-1).

4. Discussion

Considering the higher strengths of the Fe and Ti thermal media materials than Al at high temperatures (Fig. 5), the unexpected decrease of the temperature of the specimen after 1,000℃ was suspected as a result of chemical interaction between the thermal media and specimen.

The melting points of the thermal media materials (Al, Ti, and Fe) are 660℃, 1,538℃, and 1,670℃, respectively. From the phase diagrams of the chemical components between the specimens (STS 304/316) and the inner thermal media material (Al, Ti) of the capsule, the eutectic reaction temperatures (resulting in liquid phases) of Al-Fe, Fe-Ti, Cr-Ti, Ni-Ti (Fig. 6), and Mo-Ti binary systems are 655℃, 1,085℃, 1,412℃, 942℃, and 1,670℃, respectively [4]. Therefore, Al cannot be used as a thermal media at above 600℃ and Ti is also limited as a thermal media at above 942℃ for STS specimens containing Ni element. In addition, eutectoid reaction temperatures (resulting in other solid phases) of Fe-Ti, Cr-Ti, Ni-Ti, and Mo-Ti binary systems are 595℃, 665.5℃, 765℃, and 695℃, respectively. Those solid phase transformations will cause changes in physical properties of the thermal media materials.

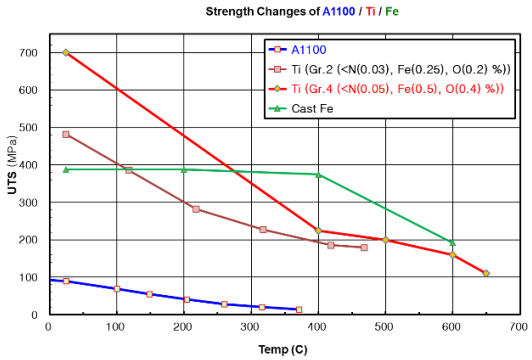

Fig. 5. Temperature dependence of the UTS strength of the thermal media materials (Al, Ti, Fe) [4].

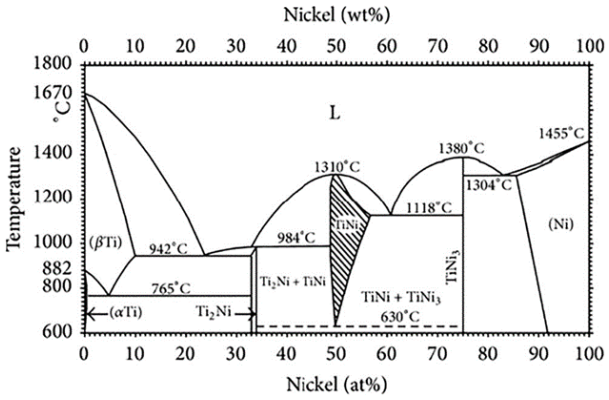

Fig. 6. The phase diagram of the binary Ti-Ni system [4].

5. Future Works

The capsule will be irradiated for 3 more cycles up to the 109 cycle. Therefore, the next irradiation tests are scheduled as follows based on the above discussion.

1) 108-2 Cycle : irradiation target for 800℃
2) 109-1 Cycle : irradiation target for 850℃
3) 109-2 Cycle : irradiation target for 900℃

6. Summary

A new capsule (15M-03K) was designed and fabricated for the irradiation test of high-temperature materials that will be used in the future nuclear systems. The capsule has a double-layered structure, the outer portion of which is made of Fe, and the inner portion is made of Ti. The second irradiation test of the capsule was performed in the CT hole of the reactor at 27 MW thermal power in 2024 and the temperature of the specimen reached 1,000℃. For a safety verification at high temperatures, the capsule will be irradiated in HANARO for more cycles.

Acknowledgement

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References

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[4] Data obtained from internet resources.