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Integrity Assessment of HANARO Irradiation Capsule for Long-Term Irradiation Testing

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1. Introduction

The High Flux Advanced Neutron Application Reactor (HANARO) has been operating as a platform for basic nuclear research in Korea, and the functions of its systems have been improved continuously since its first criticality in February 1995 [1]. To support the national research and development programs on nuclear reactors and the nuclear fuel cycle technology in Korea, irradiation capsules have been developed and actively utilized for the irradiation tests requested by numerous users [2,3]. The capsule technology was basically developed for irradiation testing under a commercial reactor operation environment. Most irradiation testing using capsules has been performed at around 300℃ within four reactor operation cycles (about 100 days equivalent to 1.5 dpa (displacement for atom)) at HANARO. Based on the accumulated experience as well as the sophisticated requirements of users, HANARO has recently been required to support national R&D projects requiring much higher neutron fluence. To scope the user requirements for higher neutron irradiation fluence, several efforts using an instrumented capsule have been applied at HANARO.

In this paper, the applied stresses on the capsule are estimated because the capsule was suspected to be susceptible to fatigue failure during irradiation testing [4]. In addition, the on-going design improvements of the irradiation capsule for higher neutron irradiation fluence at HANARO are described.

2. Irradiation Capsule at HANARO

Various neutron irradiation facilities such as rabbit irradiation facilities, loop facilities and the capsule irradiation facilities for irradiation tests of nuclear materials, fuels and radioisotope products have been developed at HANARO [2,3]. Among these irradiation facilities, the capsule is the most useful device for coping with the various test requirements at HANARO. Because of the up-stream of the coolant in the reactor, the instrumented capsule is fixed or supported at four points, which are the bottom and top of the main body, the top of the reactor chimney, and the capsule location of the robot arm. Figure 1 shows the reactor core of HANARO with an irradiation capsule installed in the central test (CT) hole.

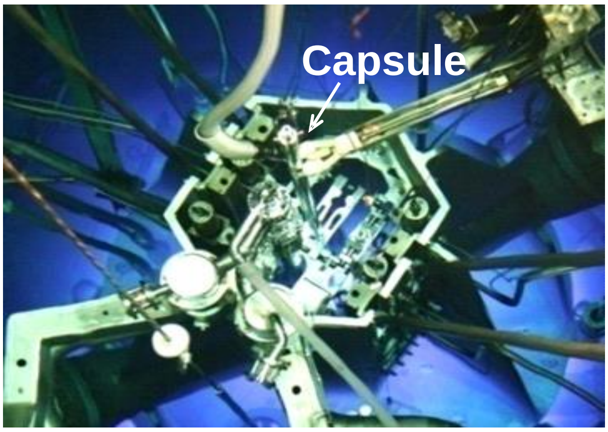

Fig. 1. Reactor core of HANARO with a capsule in the CT hole

3. Applied Stresses on the Irradiation Capsule

As the rod tip of capsule was proven to be susceptible to stress-induced fatigue cracking [4], the capsule should be safe against all possible stresses applied to the capsule parts during the irradiation testing. The applied stresses on the rod tip can be classified into stresses by the designed bottom spring, by the upward flowing coolant, by the capsule vibration, and by the residual welding stress.

3.1 Stresses by bottom spring

As shown in Figure 2, a bottom spring is located in the capsule design. The spring is at a compressed condition of 27 kgf giving a tensile stress of 5.4 MPa on the rod tip.

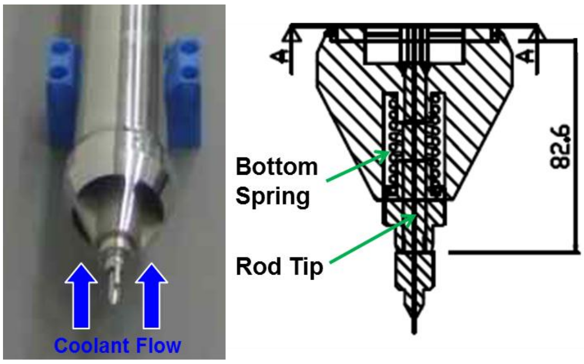

Fig. 2. Bottom Part of the HANARO capsule

3.2 Stresses by coolant upward flowing

As the loaded capsule is exposed into a forced upward coolant flow of 19.6 kg/s during irradiation, the capsule receives tensile stress by coolant flow and bending stress by coolant flow-induced vibration. To evaluate the performance and safety of a newly designed capsule, the capsule was out-pile tested in the single channel out-pile test loop. The vibration behavior of the capsule was also measured in the loop. Out-pile testing is usually performed under 110% accelerated conditions of a reactor coolant flow amount in the single channel out-pile test loop to shorten the testing period.

The stress on the rod tip of the capsule by the upward coolant flow was evaluated using the ANSYS code. Figure 3 shows the highest stress of 132.9 MPa at a 11.5 mm position from the end of the rod tip under 110% coolant condition.

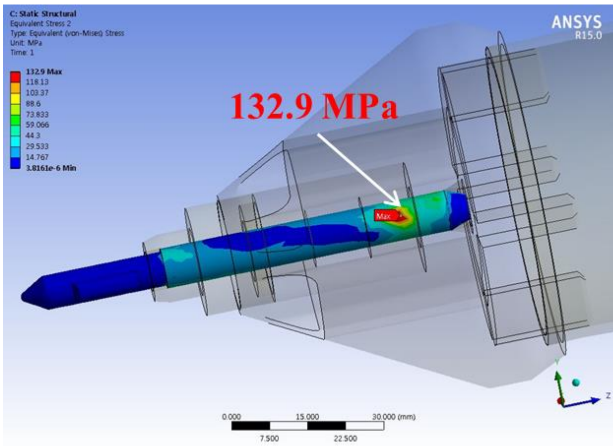

Fig. 3. Applied Stress on the Rod Tip by Coolant Flow

The vibration characteristics of the optimized capsule were measured using a laser vibrometer. The out-pile test condition of 110% of reactor coolant flow amount resulted in a coolant flow-induced vibration of 120.42 μm at a point 1.42 m above the rod tip and was evaluated to have the highest stress of 161 MPa at a 15 mm position from the end of the rod tip, as shown in Figure 4.

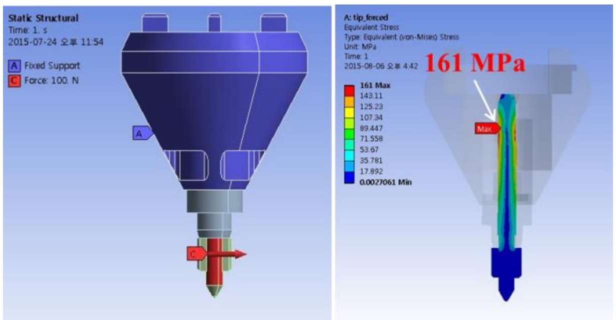

Fig. 4. Applied Stress on the Rod Tip by Capsule Vibration

3.3 Stresses by Welding

The rod tip of the capsule is welded to the bottom guide assembly of the capsule resulting in a harmful distribution of residual stress in the welding area [5]. The residual stress is known to occur at up to about 300 MPa according to the welding condition [6]. 300 MPa is the known fatigue strength of the stainless steel of the rod tip [7].

3. Summary and Future Works

The applied stresses on the rod tip were analyzed using the ANSYS program. The applied stresses on the rod tip can be classified into stresses by the designed bottom spring, by the upward flowing coolant, by the capsule vibration, and by the welding residual stress. The maximal stresses due to the first three factors were estimated as 5.4 MPa, 132.9 MPa, and 161 MPa, respectively. These stresses do not exceed the known fatigue strength of stainless steels (~300 MPa). Residual stress by welding is another possible stress and it is known to occur at up to about 300 MPa. Therefore, the combination of these stresses can be enough to cause a fatigue failure of the rod tip of the capsule.

Based on the stress analysis, a design improvement of the rod tip of the capsule was performed for up to 5 dpa of irradiation. However, for a higher neutron fluence exceeding 5 dpa, new capsule technologies including flux-boosting, re-irradiation, and re-instrumentation are under planning as the next 5-year R&D project starting from 2017 at HANARO.

ACKNOWLEDGEMENTS

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REFERENCES

[1] K. N. Choo, M.S. Cho, B. G. Kim, Y. H. Kang, and Y. K. Kim, “Material Irradiation at HANARO, Korea,” Research Reactor Application for Materials under High Neutron Fluence, IAEA-TECDOC-1659, 2011, IAEA.

[2] K. N. Choo, M. S. Cho, S. W. Yang, and S. J. Park, “Contribution of HANARO Irradiation Technologies to National Nuclear R&D”, under publication on Nuclear Engineering and Technology, **46**, 4, 501 (2014).

[3] M.S. Cho, et al., “Material Irradiation by Capsules at HANARO,” *Nucl. Technol.*, to be published.

[4] K. N. Choo, B. G. Kim, M. S. Cho, Y. K. Kim, and J. J. Ha, “Development of a Low-Temperature Irradiation Capsule for Research Reactor Materials at HANARO,” *Nucl. Technol.*, to be published.

[5] Jiamin Sun, et al., “A comparative study on welding temperature fields, residual stress distributions and deformations induced by laser beam welding and CO_2 gas arc welding,” *Materials and Design*, **63**, 519 (2014).

[6] J. Sun et al., “A comparative study on welding temperature fields, residual stress distributions and deformations induced by laser beam welding and CO_2 gas arc welding,” *Materials and Design*, **63**, 519 (2014).

[7] Sergei A. Shipilov, “Solving some key failure analysis problems using advanced methods for materials testing,” *Eng. Failure Analysis*, **14**, 1550 (2007).