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Development of a High dpa Irradiation Capsule up to 5 dpa at HANARO

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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]. Various neutron irradiation facilities such as rabbit irradiation facilities, loop facilities, and capsule irradiation facilities for irradiation tests of nuclear materials and fuels have been developed at HANARO [2,3]. Among the irradiation facilities, the capsule is the most useful device for coping with the various test requirements at HANARO. Irradiation capsules have been developed and actively utilized for the irradiation tests requested by numerous users to support the national research and development programs on nuclear reactors and nuclear fuel cycle technology in Korea [1-3]. Capsule technology was initially developed for irradiation testing under a commercial reactor operation environment. Mainly, irradiation testing of the capsules has been performed at around 300℃ within four reactor operation cycles (equivalent to 1.5 dpa) 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 a higher neutron fluence. To scope the user requirements for a higher neutron irradiation temperature and fluence, several efforts using an instrumented capsule have been conducted at HANARO [4,5].

In this paper, the progress and status of a development of a high dpa irradiation capsule up to 5 dpa are described.

2. Needs and Limitations of a High dpa Irradiation

Table I shows a list of long-term irradiation tests requested from HANARO users up to October of this year. As the irradiation technology was basically developed for irradiation testing under a commercial reactor operation environment, there is a limitation on the irradiation fluence. To scope the user requirements for a higher neutron fluence, several efforts have been applied at HANARO. A long-term irradiation capsule technology of up to 3 dpa was developed and applied for an irradiation of research reactor materials [4]. 3 dpa is equivalent to irradiation testing for eight cycles at HANARO.

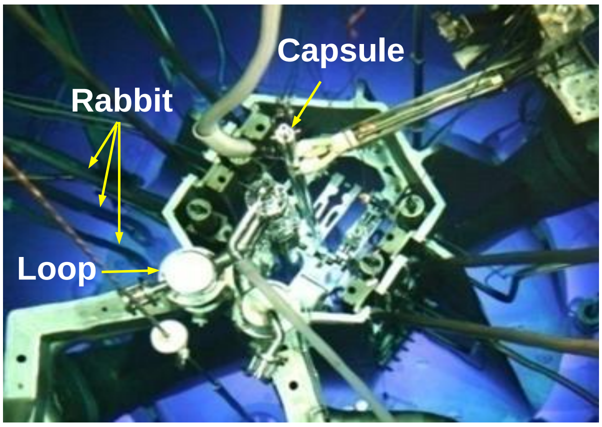

Fig. 1. HANARO irradiation facilities

Table I: Long-term irradiation tests requested by users at HANARO (Oct. 2017)

Materials	Irradiation Temp.(℃)	Rx. Cycle (dpa)	User
Fusion ARAA	300~350	>8 (>3)	KAERI
ARAA Welds	320	8~15 (3-5)	KAERI
VHTR Core	300~1000	8~24 (3~10)	KAERI
Long Life SPND	300	8~24	KHNP
U-Mo Fuel		8	KAERI
SiC Epoxy	~200	8	KAERI
Th-based Fuel		8~24	KAERI
SiC Composite	900~1600	8	KAERI
SFR ODS steel	300～500	>8 (>3)	KAERI
Fuel Cladding	RT	33 (11)	KAERI
U-Mo Fuel		>16	KAERI-ANL
VHTR Fuel	800~1300	~40 (14)	KAERI-JAEA
Fuel Assembly	300	8	KNF

ARAA: Advanced Reduced Activation Alloy, SPND: Self-Powered Neutron Detector, AR: Accident-Resistant, ODS: Oxide Dispersion Strengthened

As the irradiation capsule is exposed to a very high pressure coolant flow of 19.6 kg/s during irradiation testing, the bottom rod tip of the capsule has been suspected to be vulnerable to a vibration-inducing coolant flow. Figure 2 shows failed parts of the capsule that occurred during out-pile testing under an accelerated condition [4].

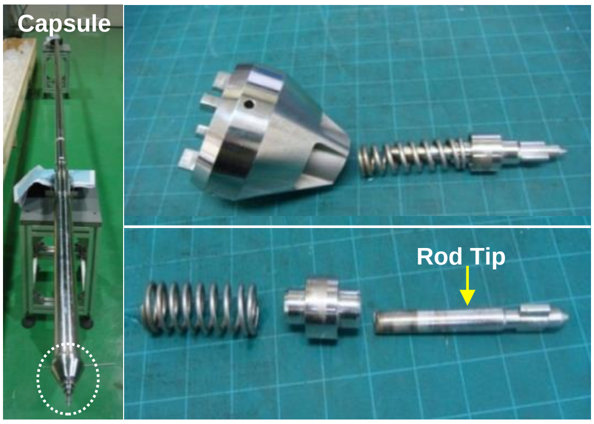

Fig. 2. HANARO irradiation capsule and failed capsule bottom parts during out-pile testing in the single channel out-pile test facility

3. Design and Verification of 5 dpa Irradiation Capsule

Based on the analysis of the failed parts during an out-pile testing [6], a new design of the rod tip of the capsule was made for long-term irradiation testing of up to 5 dpa, as shown in Fig. 3. 5 dpa is equivalent to irradiation testing for 15 cycles at HANARO.

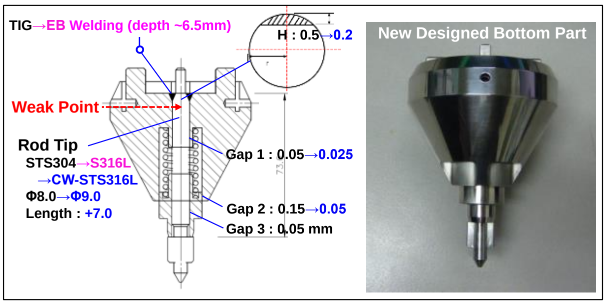

Fig. 3. The new design of the capsule bottom part for 5 dpa irradiation

Cold-worked STS 316L having a strength of 696 Mpa was selected as a rod tip material owing to a 10% higher strength than the previous STS 316L and its superior properties over STS 304 in terms of welding. The fatigue strength of a material is known [7] to be a near half value of the strength of the material. EB welding was determined to have a narrower welding area than previous TIG welding, resulting in a less harmful distribution of residual stress in the welding area. To decrease the applied stress on the rod tip, the diameter of the rod tip was increased from 8.0 mm to 9.0 mm, and the height of the tapered part of the rod tip decreased from 0.5 mm to 0.2 mm. This results in a decrease of 22.6% of the applied stress under the same conditions. The gap (gap 1 in Fig. 2) between the rod tip and the bottom guide, and the gap (gap 2) between the fixture guide and the bottom guide, were decreased from 0.05 to 0.025 mm, and from 0.15 mm to 0.05 mm, respectively, to suppress the applied stress by constraining the vibration of the rod tip. The length of the rod tip was increased by 7 mm to position the weld part of the rod tip above the stressed position. This will fundamentally eliminate the effects of residual stress by welding.

The integrity of the irradiation capsules should be fully checked before long-term irradiation testing at HANARO. Out-pile performance and endurance testing before HANARO irradiation testing was performed under 110 % accelerated conditions of a reactor coolant flow amount in the single channel out-pile test loop. The new designed capsule was safely out-pile tested for 15 operation cycles (450 days), as shown in Fig. 4.

The out-pile testing results will be submitted to the 'Reactor Safety Review Committee of HANARO' for an approval on HANARO irradiation testing of the capsule.

Fig. 4. New designed capsule after out-pile testing for 15 cycles (450 days)

4. Summary

A capsule having a new design of the capsule bottom part for long-term irradiation testing of up to 5 dpa was prepared and out-pile tested. It was designed to improve the welding and fatigue properties, to decrease the applied stress on the rod tip, and to fundamentally eliminate the effect of residual stress by welding that is known to be detrimental to a fatigue failure. The new capsule was proved to be safe for out-pile testing of 15 operation cycles under 110% accelerated conditions of a reactor coolant flow amount in the single channel out-pile test loop. The out-pile testing results will be submitted to the 'Reactor Safety Review Committee of HANARO' for an approval on HANARO irradiation testing of the capsule.

ACKNOWLEDGEMENTS

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