Experimental Analysis on Penetration Tube Ejection at the Reactor Lower Vessel for APR1400

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1. Introduction

There are 61 ICI (In-Core-Instrumentation) penetration tubes at the reactor lower vessel for APR1400. These penetrations are regarded as the most vulnerable parts during a severe accident because they can be seriously damaged by corium melt or debris relocated into the reactor lower vessel. Penetration tube failure mechanisms can be divided into two categories: tube ejection out of the reactor lower vessel and tube rupture outside the vessel. It is known that tube ejection failure is more likely to occur especially under the ERVC (External Reactor Vessel Cooling) conditions. Experimental analysis on ICI penetration tube ejection was conducted at a VESTA (Verification of Ex-vessel corium STAbilization) test facility. Experiments were performed under the non-ERVC conditions and the ERVC conditions as well.

2. Methods and Results

2.1 Experimental Setup

As shown in Fig. 1, the facility is composed of three major parts; a furnace vessel, melt delivery channel, and interaction vessel. The facility was originally designed to perform the verification tests for the development of a core catcher[1]. Afterwards, the test facility was modified to carry out various tests using melts to resolve severe accident issues. It is a typical process that simulant or corium melt is generated in the melt crucible using induction heating technique and delivered into the interaction crucible through a melt delivery channel. However, the present ICI tube ejection failure experiments were performed without melt delivery[2]. The melt is generated in the interaction crucible where test specimen is installed. Thus, the test specimen is simultaneously heated and eroded during the melt generation process. In the real reactor situation, erosion of the ICI nozzle may happen very fast unlike this test. Fig. 2 shows the photo of test specimen (left) and location of thermocouples (right). Test specimen was delivered by DOOSAN Heavy Industries such that the material and welding procedure are exactly same as prototypic one.

Test conditions are shown in Table 1. Melt materials (ZrO_2 or mixture of UO_2 and ZrO_2) are charged in the interaction crucible. Tests were performed not only under non-ERVC but also ERVC conditions. In the ERVC condition test, reactor vessel outer wall and ICI nozzle are cooled by water at a constant flow rate (~2.5 m^3/hr).

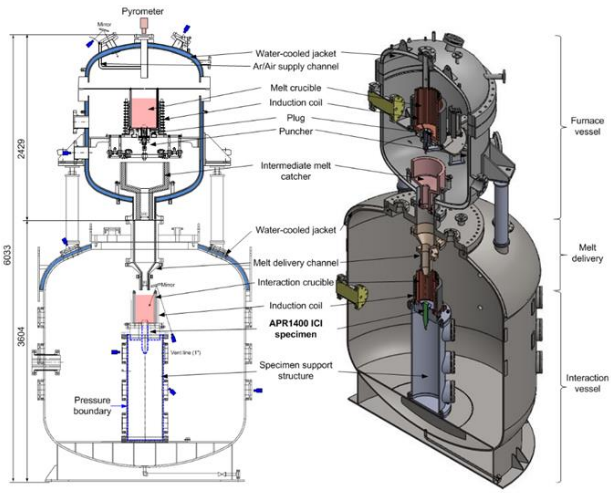


Fig. 1 Schematic of VESTA test facility

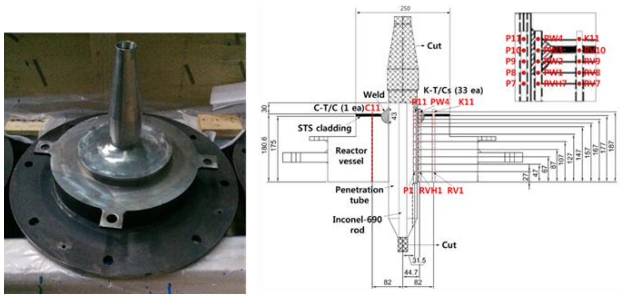


Fig. 2 Specimen of test section (left) and location of thermocouple (right)

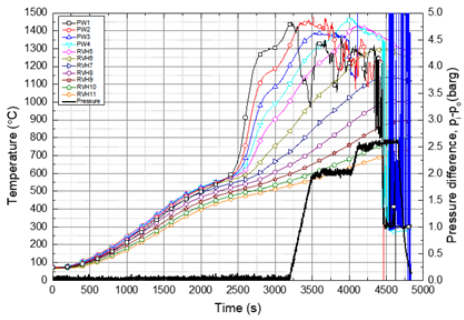
Table 1 Test conditions

Test ID	#1	#2	#3	#4
ERVC	No	No	Yes	Yes
Melt composition	ZrO_2	ZrO_2	$UO_2 : ZrO_2$ = 70 : 30 wt.%	$UO_2 : ZrO_2$ = 70 : 30 wt.%
Charged material mass [kg]	40.9	51.7	103.3	70.2
Max. ejecting pressure [bar]	2.6	1.3	2.9	3.2
Max. melt temperature [°C]	2594	2445	2639	2618

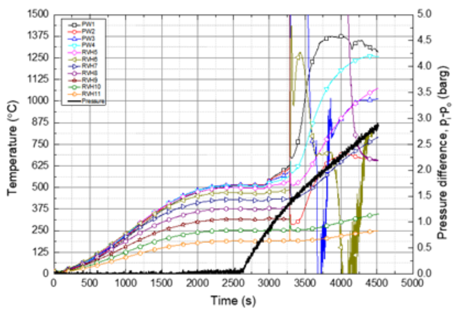
2.2 Experimental Results

Fig. 3 shows the temperature distributions of the penetration weld (PW1-PW4) and reactor vessel wall (RVH5-RVH11) for the test #1 and #3. As shown in Fig. 3(a) for the non-ERVC test (test #1), penetration weld was heated gradually and finally reached above the melting temperature (~ 1350 ℃), which implies the penetration weld failure occurred. Large fluctuations in the late phase are due to the thermocouple failure after reaching the upper limit. On the other hand, the penetration weld and reactor vessel wall temperatures for the ERVC test (Fig. 3(b)) show lower values than those of non-ERVC test and remain below 500 ℃ for a long time. Then, PW1-PW4 increases sharply after about 3250 s. However, some penetration weld temperatures remain still below the melting temperature, which implies a partial melt of the penetration weld. Based on the ERVC water flow rate and temperature difference between inlet and outlet of water, the maximum removal heat flux by ERVC was evaluated at about 0.47 MW/m^2. Compressed air began to be supplied to pressurize the ICI nozzle up to 3.2 barg. The temperature measurement data for test #2 and test #4 are similar to those of test #1 and test #3 respectively.

Tube ejection failure did not take place for all the tests. The temperature measurement data are used for the development of ICI tube ejection failure model so called “PENTAP plus”[3, 4, 5].



(a) Non-ERVC condition



(b) ERVC condition

Fig. 3 Temperature distributions of the penetration weld and reactor vessel wall

Fig. 4 shows the photos of test specimens before and after the experiment. In the non-ERVC test, inside of the ICI nozzle was perfectly blocked before the test. Whereas, in the ERVC test, it was partially blocked at the bottom expecting some of the melt would flow inside the nozzle. The penetration weld and ICI nozzle above the inner reactor vessel wall are completely eroded for the non-ERVC tests (Fig. 4(a)). For the ERVC tests (Fig. 4(b)), the ICI nozzle above the inner reactor vessel wall is completely eroded but the penetration weld is partially eroded.

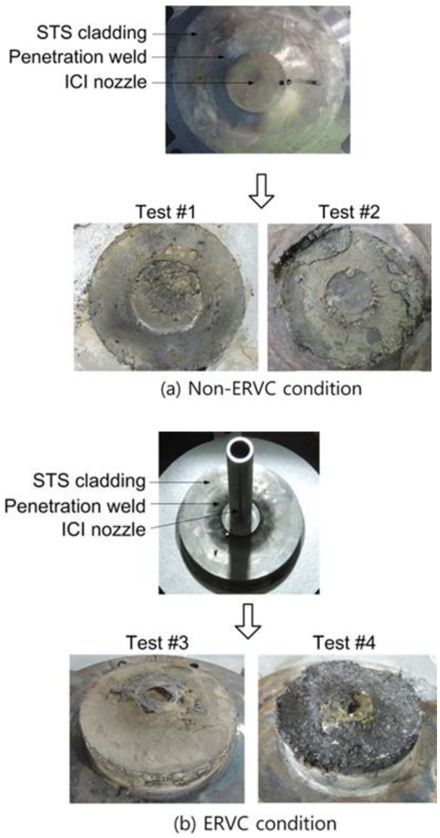


Fig. 4. Photos of test specimen before and after the experiment

3. Conclusions

Experimental analysis on ICI penetration tube ejection was conducted at the VESTA test facility with using a prototypic test specimen. ICI nozzle was compressed up to 3.2 barg during the test. Tube ejection failure did not take place under the test ranges. The penetration weld and reactor vessel wall temperatures were different between non-ERVC and ERVC conditions. The temperature measurement data along the nozzle wall and reactor vessel wall are very important for the development of penetration tube ejection model. They are used for the “PENTAP plus” code which can judge the failure of penetration tube ejection.

ACKNOWLEDGMENT

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