Cold Crucible Technique for Interaction Test of Molten Corium with Structure

Kwang Soon Ha [a*], Sang Mo An [a], Beong Tae Min [a], Hwan Yeol Kim [a]
[a] *Korea Atomic Energy Research Institute, 989-111 Daedeok-daero, Yuseong-gu, Daejeon, Korea*
[*] *Corresponding author: tomo@kaeri.re.kr*

1. Introduction

During a severe accident, the molten corium might interact with several structures in a nuclear power plant such as core peripheral structures, lower plenum, lower head vessel, and external structures of a reactor vessel. The interaction of the molten corium with the structure depends on the molten corium composition, temperature, structural materials, and environmental conditions such as pressure and humidity [1-3]. For example, the interaction of a metallic molten corium containing metal uranium (U) and zirconium (Zr) with the oxidized steel structure (Fe_2O_3) is affected by not only thermal ablation but oxidation-reduction reaction because the oxidation quotients of the U and Zr are higher than that of Fe. KAERI set up an experimental facility and technique using a cold crucible melting method to verify the interaction mechanism between the metallic molten corium and structural materials. This technique includes the generation of the metallic melt, melt delivery, measurement of the interaction process, and post analyses after the test.

2. Methods and Results

Figure 1 shows an experimental facility to verify the interaction mechanism between the metallic molten corium and structural materials. The molten corium is generated in the melt crucible and delivered into the interaction crucible, where the specimen of the structural material interacts with the molten corium. This melt-delivery method was adopted for preventing the specimen from pre-heating and chemical change during the long melt generation process (2~3 hours).

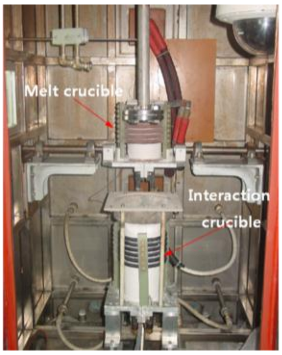

Fig. 1 Experimental facility

2.1 Melt Generation System

A cold crucible melting technique was applied to generate metallic corium melts. The cold crucible is made by palisade-like copper tube assembly, and cold water flows into the crucible to cool down the interface between the melt and the tube assembly. As shown in Fig. 2, magnesium oxide (MgO) powder is sintered on the inside wall of the crucible to protect the crucible not only thermally but also electro-magnetically. A water-cooled induction coil is located outside of the crucible to supply electro-magnetic energy. A generator supplies electric power to the induction coil up to 225kW with 76Hz. The MgO-sintered melt crucible has 70mm inner diameter and 130mm height; therefore, about 3kg molten corium can be generated. Some thermocouples which are shielded by tungsten or alumina tubes and an optical pyrometer (IRCON Modline 3R, 1500-3500°C, <0.6% error) were used to measure the molten corium temperature. Especially, argon (Ar) gas purging tube between top of the cold crucible and the optical pyrometer was installed to remove some aerosols generated from the molten corium and finally to secure the optical path. A hollow rod [20mm(O.D.), 12mm(I.D.), 130mm(L))] was also installed in the melt to make rays emitted from the molten corium into blackbody radiation.

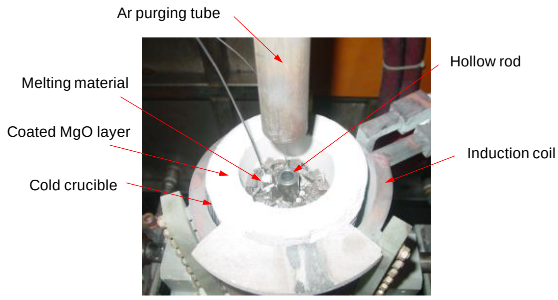

Fig. 2 Melt generation system

Figure 3 shows the typical temperature history of the molten corium in the melt crucible along with the generator power. The melt composition was 46% Fe, 31% U, 16% Zr, and 7% Cr of total mass. The melt temperature reached around 2,000°C at 95kW of the generator power.

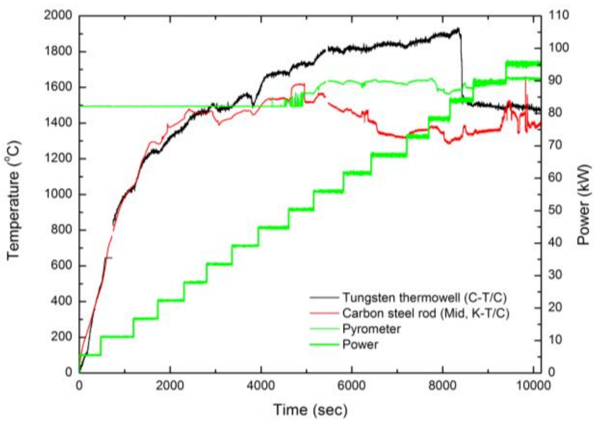

Fig. 3 Temperature history in the melt crucible

2.2 Interaction System

If the molten corium temperature reaches the expected condition, the melt is poured into the interaction crucible by the remote-controlled rotating system. As shown in Fig. 4, the interaction crucible has a similar feature to the melt crucible, that is, water-cooled and MgO-coated crucible. After the melt delivery process, the interaction crucible is instantaneously heated up through the water-cooled coil as switching the power generator from the melt crucible to the interaction crucible. A specimen is installed inside the interaction crucible; therefore, the interaction of the hot melt with the cold specimen occurs immediately after the melt delivery. Several thermocouples are embedded in the specimen with different radius and depth to measure an ablation rate. The ablation profile of the specimen should be assumed as a spherical shape because the side wall of the specimen in the cold crucible maintains constant coolant temperature. If the i-th ablation radius R_i is obtained by thermocouple signal, the ablation rate W can be calculated by the following equation.

$$R_i = W(t_i - t_0) = \sqrt{x_i + y_i + z_i}\ , \qquad (1)$$

where x_i, y_i, z_i are x-, y-, and z-coordinate of the i-th thermocouple location, and t_0, t_i are an ablation starting time and melt reaching time on the i-th thermocouple location. The unknowns in Eq. (1), that is, the ablation rate W and ablation starting time t_0, can be obtained by the measured ablation times and least-squared-fitting method.

Figure 5 shows that typical temperature history of the molten corium and specimen in the interaction crucible. The specimen is a special concrete including 68wt% Fe_2O_3.

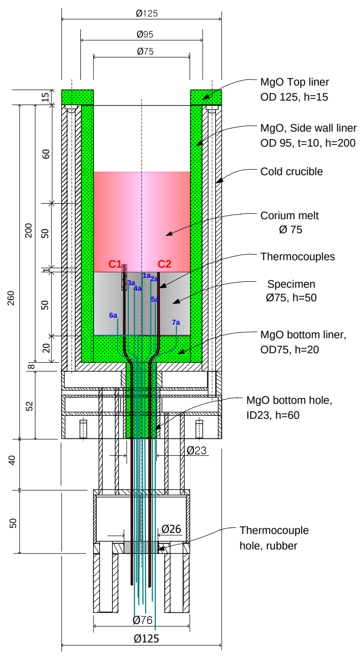

Fig. 4 Interaction crucible

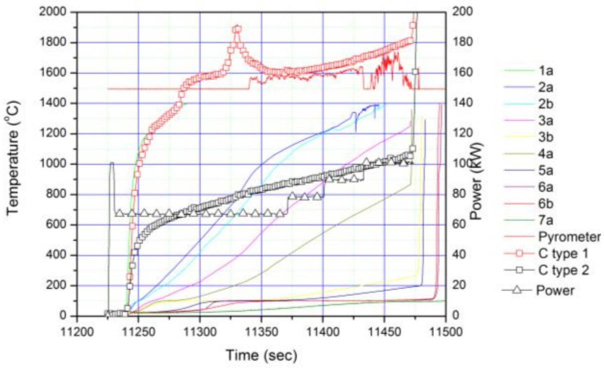

Fig. 5 Temperature history in the interaction crucible

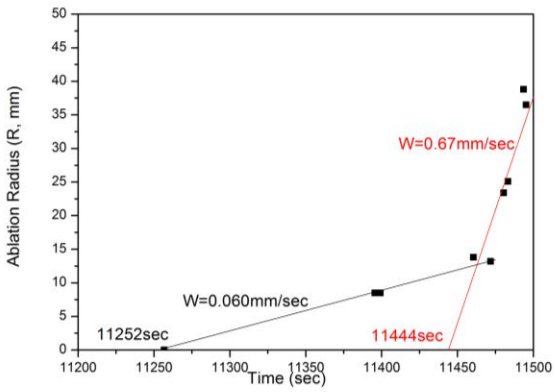

Fig. 6 Ablation rate of the specimen

As shown in Fig. 5, temperatures measured by thermocouples embedded in the specimen abruptly increased when the melt reached on each thermocouple tip. Figure 6 shows the calculated ablation rates by using the thermocouple readings in Fig. 5 and Eq. (1). As shown in Fig. 6, two typical ablation rates of the specimen were identified; this seems to be why the interaction mechanism might be changed from the thermal to chemical interaction.

3. Conclusions

An experimental facility and technique were set up using a cold crucible melting method to verify the interaction mechanism of the metallic molten corium and structural materials. This technique simulated successfully interaction phenomena of the metallic corium melt and concrete with oxidized steel.

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