Melting Experience of Reactor Material using a Cold Crucible

S. W. Hong, B. T. Min, J. H. Kim, J. H. Song, H. D. Kim
Korea Atomic Energy Research Institute, P. O. Box 105, Yusong, Daejon, KOREA, 305-600, swhong@kaeri.re.kr

1. Introduction

It would be important to use a real reactor material which is called corium in order to understand the real severe reactor accidents phenomena related to the cooling of corium because corium with a very high melting point may result in different results from the general thermal hydraulic phenomena of a material with a low melting point. Therefore, it is indispensable to establish the melting method for a reactor material with a high melting point. KAERI has been carrying out an intermediate scale FCI test using real corium since 1997. As a part of the KAERI FCI program [1] that is called TROI, the melting and discharge of reactor material have been under development using the cold crucible melting method. The melting experience for a reactor material using the cold crucible is presented.

2. Experiments

2.1 Melting Principles

Inductive skull melting of oxides is based on a direct inductive heating of an electrically conducting melt by an alternating electro-magnetic field. Heating is thereby accomplished by the ohmic losses caused by the eddy currents induced in the melt. The metal ring serves as an initiator. The initiator of the metal ring becomes oxidized and a sufficient energy reaches the adjacent material to cause a melting. An increase in the R.F coil current indicates that more efficient coupling would occur with the increase in electrical conductivity accompanying the phase transition to the molten oxide. The melting zone is gradually expanded from the initiator with a time and power increase. Within ten minutes, the stable melt is obtained. The skull crust layer formed naturally by a cooling from outside, plays a crucial role in retaining the molten material without a direct contact with the cage. Fig. 1 shows the conceptual shape of the longitudinal cross section of the typical cold crucible. The more detail descriptions are explained in the reference [2, 3]

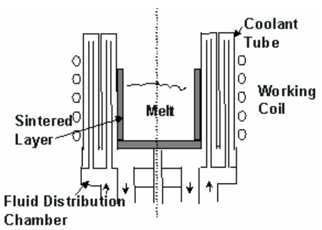

Fig. 1. Induction skull melting

2.2 Test Facility

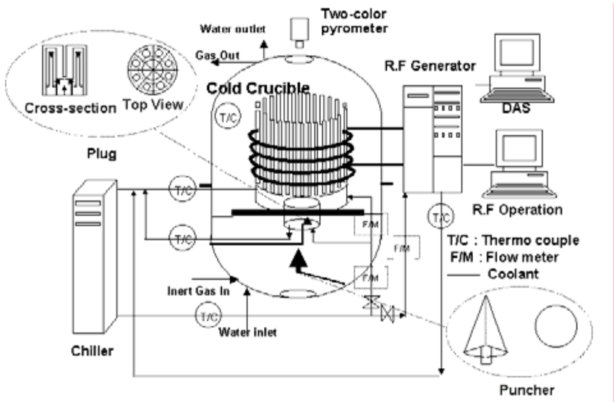

Fig. 2 Schematic diagram of the test facility

Fig. 2 shows the schematic diagram of the test facility. The furnace vessel is manufactured as a double jacket where the cooling water flows into the gap between the internal and external vessel. The furnace vessel can also be used to provide inert gas such as argon for the prevention of an oxidation of a metal such as a tungsten tube that is going to be used for the melt temperature measurement. Height and diameter of the furnace vessel are 1.7m and 1.36m, respectively. The operating program in the PC controls the RF generator input. The cold crucible which consisted of several cooper tubes located in the furnace vessel. Table 1 shows the dimension of the cold crucible and induction coil that are made of copper.

Table 1. Crucible and coil data

Names	Value
Inner radius of crucible [mm]	71
Height of crucible [mm]	200
Number of cooling fingers	36
Diameter of cooling fingers [mm]	14
Coil windings [turns]	12
Diameter of coil tube [mm]	14
Inner diameter of coil [mm]	245
Height of coil [mm]	160

2.3 Test Results

Table 2 shows the composition of the reactor materials that are used in the melting experiments.

Table 2 Reactor material compositions

Composition	Weight %	TROI-No.
UO2/ZrO2	70:30	40
UO2/ZrO2	80:20	39
UO2/ZrO2	90:10	32
UO2/ZrO2	50:50	29
(UO2/ZrO2)/Fe	90:10	44

Fig. 3 shows the inner picture of the crucible after ejecting the molten materials. The thicknesses of the sintered layer that is formed between the melt and the crucible are about 2mm and 3mm at the side-wall and bottom surface, respectively. The last one shows the picture taken at the bottom of the crucible. The hole is formed at the bottom of the crucible by a puncher. Melt of 60 to 70 % of the initial mass charged into the crucible is released. The rest remains in the crucible as a part of the sintered layer between the melt and the crucible and of the upper crust formed above the melt.

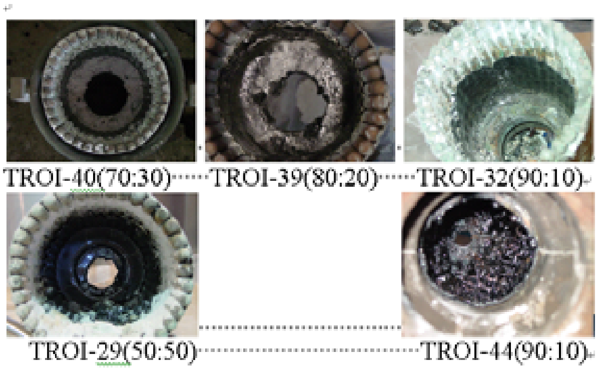

Fig. 3 Inner picture of the crucible.

The heat absorption to the melt is calculated using the coupling factor Q[4]. Q is defined by the ratio of the loss of power to the maximum energy that can be stored in the system. Q is expressed as below in the direct resonance circuit.

$$Q = \frac{\omega L}{r} = \frac{Z_L}{Z} = \frac{V_c/I_L}{V/I} = \frac{P_L}{P} \approx \frac{P_c}{P} = \frac{A_C V_C}{A_{DC} V_{DC}} \qquad (1)$$

where $\omega = 2\pi f$, r is a resistance, L is a reactance, Z is a impedance, Z_L is a coil impedance, V_L is a coil voltage, I_L is a coil current, P_L is a tank coil power, P_c is a tank condenser power, A_{DC} is a DC current, V_{DC} is a DC voltage, A_c is a tank condenser current, V_c is a tank condenser voltage.

The melting state in the crucible can be estimated from the change of the Q value. The energy is absorbed to the initial charge material with a starting of the power input. Then, the melt temperature at the center of the charge material increases. Therefore, Q decreases because the melt zone expands, resulting in an increasing coil load. Fig. 3 shows the change of Q with time depending on the compositions. The corium including Fe shows other characteristics. The heating efficiency of the melting depends on the characteristics of the energy absorption. It is characterized from the electrical and magnetic properties of the material. The maximum melt temperature reached over 3,000 °C for each composition.

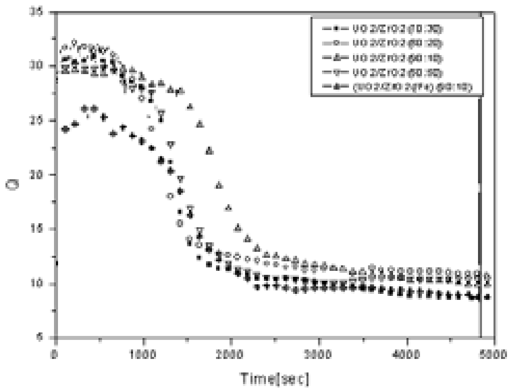

Fig. 4 The change of Q for various compositions with time

3. Conclusion

About 10kg of molten melt of the reactor materials is obtained using the cold crucible melting method, which does not need a separate crucible such as tungsten. The melting and discharge test for the UO_2/ZrO_2 mixtures is successfully carried out with the application of the KAERI FCI experiment. This melting method can be applied to the melting of reactor materials with a very high melting point.

ACKNOWLEDGMENTS

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