Layer Inversion Phenomenon with Metal-added Corium in the TROI Facility

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1. Introduction

Recent MASCA tests show a layer inversion due to a heavy metal (uranium) extraction on the bottom of the melt from a reduction of UO_2 by cladding and structural metal components (Zr and Fe)[1,2]. As uranium metal is known to be chemically reactive with water at a high temperature, steam explosion tests with metal-added corium need to be investigated. Before these tests, a melting test incorporating prototypic metal-added corium has recently been carried out in the TROI experiment. This test (TROI-49) was performed to confirm the layer inversion phenomenon due to a uranium extraction.

2. Test Facilities

For the test, a cold crucible was used as a melt container. The charged material was melted by using an induction heater. A schematic diagram of the charging pattern in the cold crucible for this melting test is shown in Fig. 1. The melt temperature in the cold crucible was measured by an optical two-color pyrometer (IRCON 3R-35C15-0-0-0-1, 1500~3500°C, precision: within 0.6% of reading) installed at the top of the furnace vessel. The pyrometer directed the center hole in the charged material shown in Fig. 1. The composition of the charged mixture in this test was 65.32 : 10.81 : 12.27 : 11.6 at a weight percent of UO_2 : ZrO_2 : Zr : SS. This composition is very similar to that used in the OECD MASCA program.

3. Test Results

For the test, the crucible was charged with a mixture of 70 : 30 corium ($UO_2/ZrO_2/Zr$ = 73.89/12.23/13.88) and stainless steel at a 88.4 : 11.6 weight percent except for a ZrO_2 coating on the cold crucible inner wall. The charged weight was 15.211 kg (total 15.961 kg including coating). The g-moles of UO_2, ZrO_2 and Zr were 36.8, 13.4 and 20.5 and the mole percents were 52.05, 18.95 and 29.0, respectively. The U/Zr molar ratio was 1.086. The oxidation rate of zirconium was 39.52 %.

Then the charged material was melted and then maintained for about 4000 seconds to spread the melting zone by using an induction heating. The maximum melt temperature reached 3092 K, which is above the melting temperature of the mixture. Thereafter, the melt was allowed to cool down and solidify by turning the heating power off.

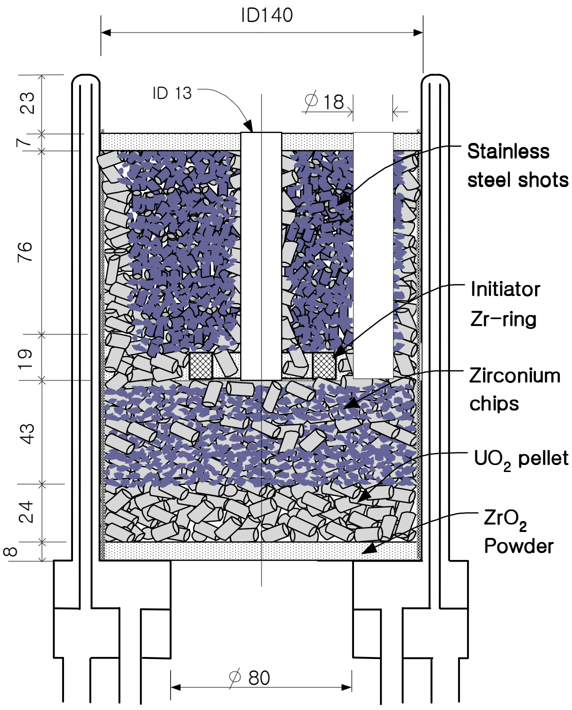

Figure 1. Charging pattern for TROI-49

Then the crucible was dismantled and the solidified melt was disassembled, as shown in Fig. 2.

The solidified melt was taken after the removal of the top liner part. The top surface of the solidified melt had cracks and it was black. The corium lump consisted of two parts, the upper part was a black color (Fig. 3) and the lower part was a silver color (Fig. 4). They were easily separated. The melt might be separated by two layers. The upper part with a black color was oxide and the lower part with a silver color was a metal. Some broken pieces were classified and sampled for a chemical analysis. The mass of the unmelted top liner, upper lump and lower lump was 5.075 kg (32.43 %), 8.21 kg (52.46 %) and 2.365 kg (15.11 %), respectively. Total product was 15.65 kg. Since the total charged mass was 15.961 kg including the coated zirconia, the loss was 0.311 kg. The loss probably came from the vent gas, cold crucible weight change (due to the coolant mass in the fingers), measurement errors and so on.

The lower part is probably metal, since it sparked when hit with a hammer. However, its density (9.25 g/cm^3) was much lower than uranium metal (19 g/cm^3). Therefore, the lower part may be alloyed by a stainless steel, zirconium and uranium metal.

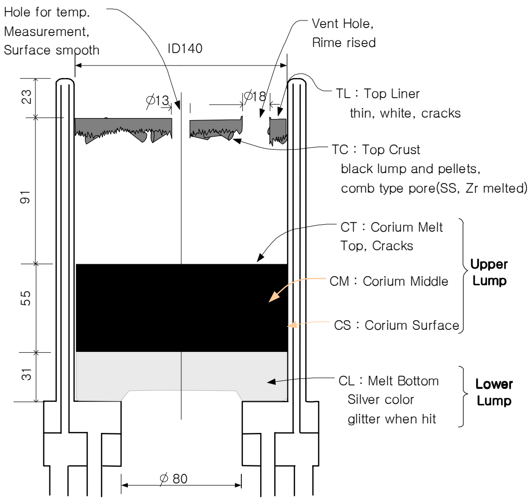

Figure 2. Solidified melt configuration after cooling and sampling positions

Figure 3. Upper lumps of the solidified melt

Figure 4. Lower lumps of the solidified melt

The XRD analyses for the samples of the lumps were performed to find their compositions. Since the samples from CT, CM and CS in the upper layer showed a similar pattern with each other, which contained ZrO_2 and UO_2, the result for the middle part (sample CM) is presented in Fig. 5. The lower layer (sample CL) contains Fe_2U and ZrO_2, as shown in Fig. 6. From this XRD analysis, it is concluded that the upper layer is an oxide and the lower layer is a metal.

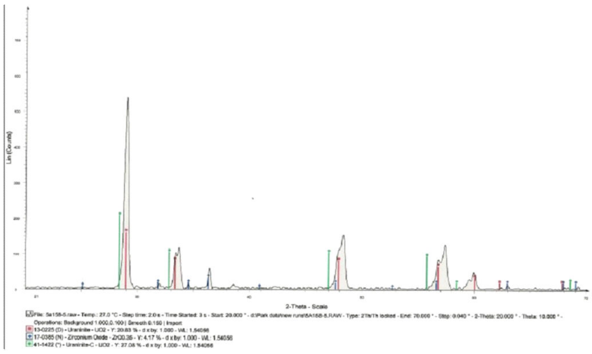

Figure 5. XRD result for the upper layer (CM)

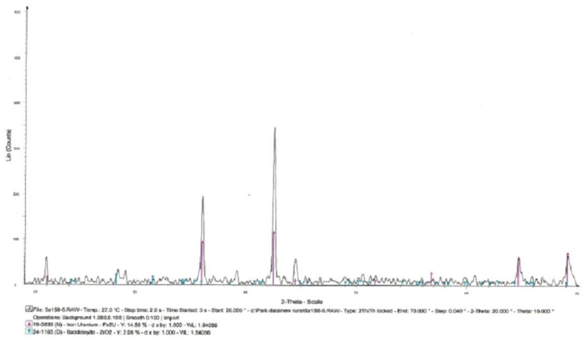

Figure 6. XRD result for the lower layer (CL)

4. Conclusion

Molten corium showed a layer inversion when cladding and structural metal (Zr and Fe) was added. Uranium metal in the form of an alloy with iron was extracted on the bottom layer of the melt. Afterwards, steam explosion tests need to be implemented to consider the effects related to this phenomenon such as a uranium metal oxidation in water etc.

ACKNOWLEDGMENTS

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