Experimental Investigation on the Melt Pool Configuration with the COSMOS

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1. Introduction

In general, a two-layer melt pool with a light metallic layer of Fe-Zr on top of oxidic pool was assumed to be a bounding melt configuration in the safety analyses for the severe accidents. The experimental results of the OECD MASCA [1], however, have shown that when a sufficient amount of non-oxidized zirconium (Zr) is available, then metallic uranium (U) migrates to the metallic layer. The transfer of species between the U, O, Zr melt and the steel can result in a significant density increase of the metallic phase. The density increase of the metallic phase can lead to inverse stratification with an additional heavy metal layer below the oxidic pool. The presence of the metallic layer at the bottom of the lower head is likely to decrease the thickness of the top metallic layer and consequently to increase the risk of the focusing effect.

At KAERI, thermodynamic analyses using the GEMINI code were performed to examine the final melt pool configuration during the severe accidents in the APR1400. In this study, based on the thermodynamic analysis results, for an investigation on the molten pool configurations considering the layer inversion of the heavy metallic layer, a series of test, named as the COSMOS (Corium configuration of the molten State in the Most Severe Accidents), are in progress. Since the melt pool configurations were different in the representative accident sequences of the APR1400, a series of test will be performed for the initial melt pool conditions of the major severe accident sequences of the APR1400.

2. Description of the COSMOS

In the COSMOS test, induction heating method using a cold crucible was implemented for melting of the prototypic UO_2-ZrO_2-Zr-Fe mixture. The maximum electric power and frequency of the generator were 100 kW and 120 kHz, respectively. Fig. 1 shows the schematic diagram and photograph of the COSMOS test facility. The inner diameter and the height of the crucible were 9.45 cm and 25 cm, respectively. In the test facility, steam supply line and by-pass line were installed in order to perform a transient test of corium behaviour. In this study, after the completion of the layer inversion test under the steady-state condition, the transient tests will be performed under the steam environment and the additional supply of Fe during the reaction.

The temperature of the melt pool surface was measured using the two-colored Pyrometer (Model name: IRCON 3R-35C15-0-0-0-1). Measuring range of the two-colored Pyrometer is from 1500 to 3500 ^oC with a measurement error of 2.0% of the reading. Metallurgical inspection methods such as EPMA (Electron Probe Micro Analyzer) and XRD (X-Ray Diffraction) were implemented in order to precisely examine the distribution and composition of the melt layer as a post-inspection of the test. The metallurgical homogeneity and the chemical compounds of a sampled ingot were analyzed by EPMA and XRD, respectively.

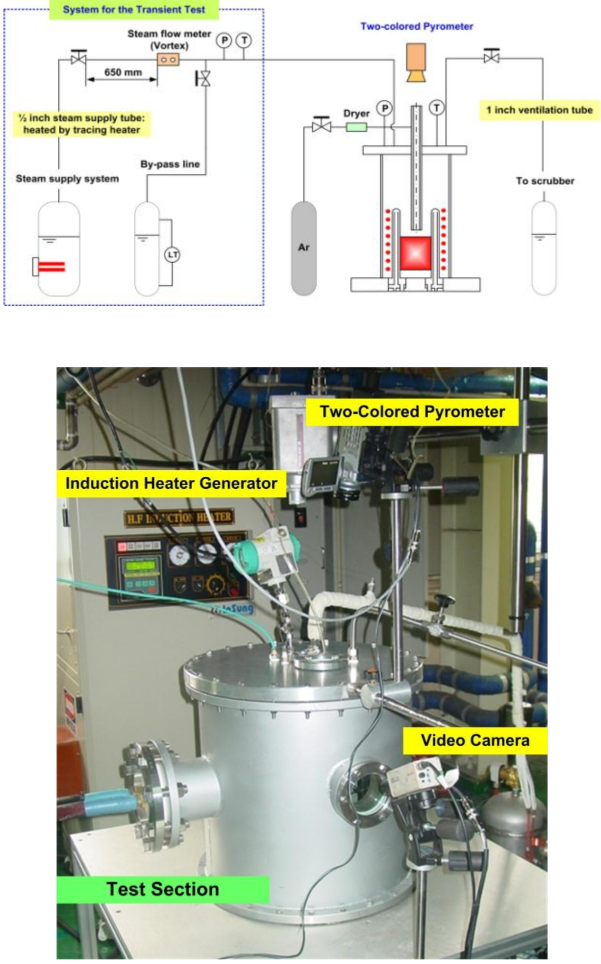

Fig. 1. Schematic diagram and photograph of the COSMOS test facility.

As the first test in the framework of the COSMOS, the COSMOS-001 test was performed for the melt pool configuration corresponding to that of the TLFW sequence in the APR1400. According to the thermodynamic analysis results, a layer inversion of heavy metallic layer is expected for this melt configuration of the TLFW sequence. In order to obtain the ideal melt mass, UO_2-ZrO_2-Zr-SS (stainless steel) mixture was charged. Exact melting of the mixture in terms of the melt mass, however, is very hard task in the test which implements a cold crucible induction heating method for melting of the prototypic UO_2-ZrO_2-Zr-SS mixture. From this reason, in the COSMOS-001 test, actual melt compositions were different from those intended for the TLFW simulation.

3. Experimental Results

The schematic diagram and the photograph of the solidified corium in the crucible are shown in Figure 5 and Figure 6, respectively. The upper crust anchored to the cold crucible and was partially cracked. The space between the melted ingot and the upper crust was made due to the porosity of charged mixture. The mass and the thickness of the upper crust were 0.56 kg and 1.0 cm, respectively. The mass and the height of the melted ingot were 5.545 kg and 10.9 cm, respectively. As shown in Fig. 2, there were some un-melted UO_2 pellets and ZrO_2 powder in the vicinity of the melted ingot. The melted ingot was separated into two layers as shown in Fig. 3. The upper part was silver color and the lower lump was black color which indicates that the upper part may be metal and the lower lump may be oxidic mixture.

In the COSMOS-001 test, the total charged mass was 6.855 kg and the total collected mass was 6.795 kg. Therefore, the mass loss was 0.06 kg which could be attributed to the release by aerosols during the melting process and also the loss during the disassembling process of the cold crucible after the test. Despite some mass loss, the masses of the charged mixture and the collected products can be considered to be well balanced.

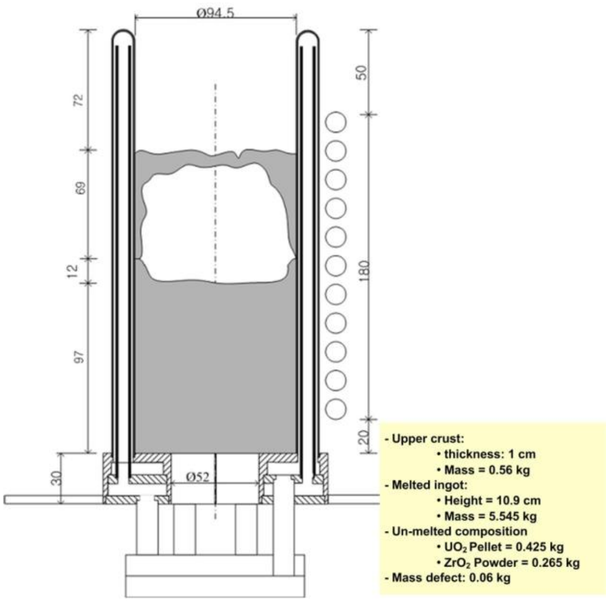

Fig. 2. Schematic diagram of the solidified corium

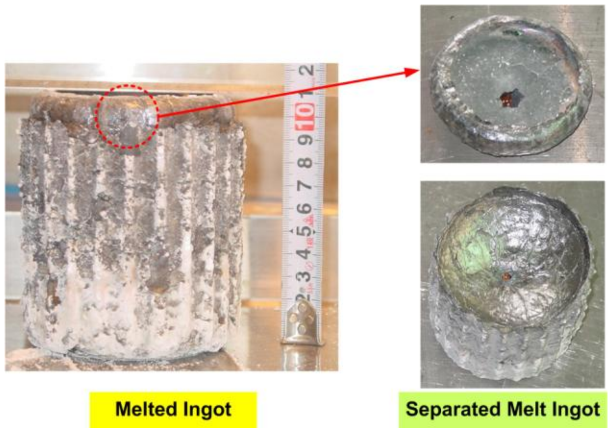

Fig. 3. Photograph of the solidified ingot

In this study, metallurgical inspection was performed with an aim of precise investigation on the distribution and composition of the melt layer as a post-inspection of the test. The metallurgical homogeneity and the chemical compounds of a sampled ingot were analyzed by EPMA and XRD, respectively. According to the EPMA analysis, it can be confirmed that the upper part of the melted ingot was metal mixture and the lower lump was oxidic mixture and there were some metal clods inside the lower lump.

4. Conclusions

As the first test in the framework of the COSMOS, the COSMOS-001 test was performed with an aim of experimental investigation on the detailed phenomena of a layer inversion for the melt configuration corresponding to the TLFW sequence in the APR1400. Due to the inherent technical difficulty, however, actual melt compositions were different from those intended for the TLFW simulation. In the COSMOS-001 test, U/Zr ratio and Zr oxidation rate were 0.93 and 69%, respectively. The melted ingot was separated into two layers. The metallurgical inspection results on the chemical information coincide with the visual observation on the centerline cut ingot in that the upper part is metal and the lower lump is oxidic mixture with some metal clods.

The present COSMOS-001 test results will be used not only to provide physical insight into the layer inversion phenomena of the heavy metallic layer but also to produce metallurgical inspection test data to validate the thermodynamic analysis methodology using the GEMINI code.

REFERENCES

[1] M. Barrachin and F. Defoort, "Thermophysical Properties of In-Vessel Corium: MASCA Programme Related Results," *Proceedings of MASCA Seminar 2004*, Aix-en-Provence, France, June 10 ~ 11 (2005).