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Analysis for Factors Affecting Molten Corium Concrete Ablation and Coolability

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1. Introduction

Molten corium concrete interaction (MCCI), a complex thermo-chemical phenomenon has been studied continuously for reducing the uncertainty of the modeling. However, the uncertainty of this phenomenon is still high. There are many uncertain values needed to simulate the MCCI. Fig. 1 shows models, parameters, and the values in scenario conditions resulting in sub-phenomena in MCCI. First, depending on accident scenario conditions, the following values have ranges of values. Second, there are also a lot of model and correlations to calculate the mass and energy transfer. Finally, the values in the two groups are used for specific phenomena in MCCI condition.

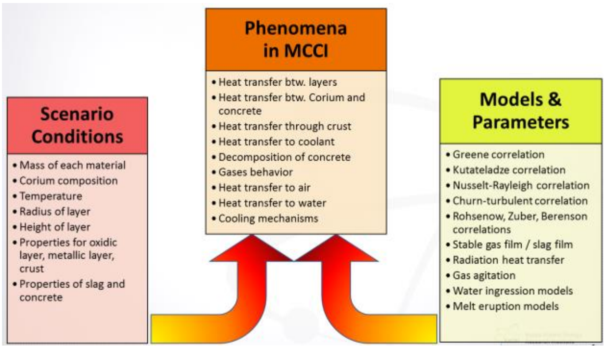

Fig. 1. Variables, Models and Correlations in MCCI

The first purpose of this research is to find out key variables in MCCI simulation. The second purpose of this research is to analyze the effects of the key variables found along the first purpose. The two purposes were set for the amount of ablated concrete volume by molten corium and heat flux from molten corium to top water.

2. Analysis for Uncertain Variables

To find out the key variables, a parametric approach on the uncertain variables was applied. The uncertain values can be defined by the variables calculated from many correlations with a parameter and model with high uncertainty. Accordingly, the variables were simplified and defined as a parameter. It includes initial conditions, corium and concrete properties, heat transfer to bottom, side and top.

To apply this simplified approach using parameters, a new quasi-stationary parametric simulation code has been developed for corium concrete interaction. The code set an energy equation for concrete ablation and absorption with thermal equilibrium on a corium melt. This analysis method was applied to WECHSL code developed by FZK in Germany [1].

Two experiments were adopted as simulation cases. The first is a MOCKA-7.1 experiment. Initial melt mass was 83.0 kg. Concrete type was Limestone/Common Sand (LCS) with steel rebar. The density was 2526 kg/m³. Initial cylindrical melt geometry was 0.125 (radius) m and 0.55 (height) m. Initial melt temperature was 2113 K. Melt heating technique was thermite reaction with Zirconium oxidation. Power supply operation was 303 kW. It was open to air. Experiment time was 38 min.

The simulation results for the variables in MOCKA-7.1 were shown in Fig. 2.

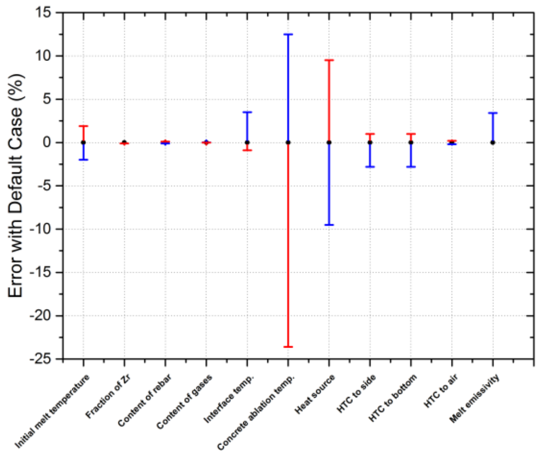

Fig. 2. Results of Sensitivity Analysis for MOCKA-7.1

The Second is a CCI-2 experiment. Initial melt mass was 400 kg. Concrete type was Limestone/Common Sand (LCS). Density was 2320 kg/m³. Initial melt geometry was 0.5(width) x 0.5(thickness) x 0.25(height) m³ in the atmospheric pressure. Initial melt temperature was 2123 K. Power supply operation was constant at 120 kW. It was open to air for 5 hours. Water was supplied after 5 hours. Therefore, it was simulated for 6 hours in this study.

The simulation results for the variables in CCI-2 were shown in Fig. 3.

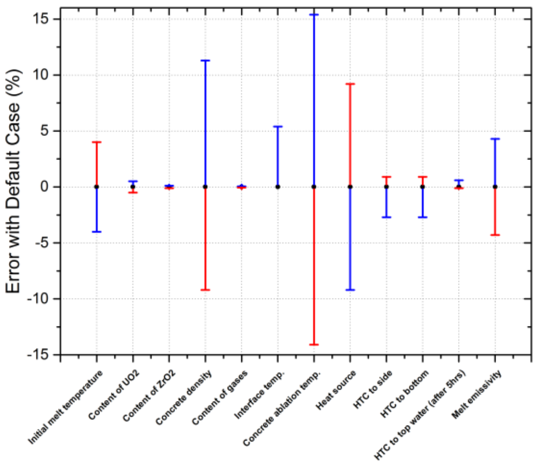

Fig. 3. Results of Sensitivity Analysis for CCI-2

3. MELCOR Models and Analysis

The analysis results imply the affecting range of the key variables. They were originally calculated and limited by the existing models. First of all, the concrete decomposition temperature must be well-defined. Heat transfer coefficients on side and bottom interfaces are dependent on the gas modeling. Heat transfer by slag film model is still limited by the heat transfer coefficient of the molten corium pool. The heat transfer coefficient can also have a wide range of values.

The main variables which were estimated as a main affecting parameter were sorted and adopted in the analysis for uncertain variables. The MELCOR inputs and models related with the affecting parameters were varied and analyzed. Some of the parameters were converted to related variables with a range. The MELCOR version 2.2 was used for the simulations [2]. For the coolability of the corium in the MCCI condition, the effects of the coolability mechanisms including water ingression and melt eruption were small.

The ablated concrete volumes in the cases were compared with the default case of CCI-2. Fig. 4 shows the error for the ablated concrete volumes for first five hours. In the CCI-2 experiment, the water was supplied after the five hours from the initiation of the experiment. The heat flux from the molten corium to the top water was calculated in each case. Fig. 5 shows the error for the heat flux in the sensitivity analysis cases. In the Figures 4 and 5, the blue bar means the decrease of the value in the sensitivity analysis for each case. The red bar means the increase of the specific value in the sensitivity analysis for each case.

4. Conclusion

The sensitivity analysis was carried out for finding out the key variables using the parametric code. Concrete ablation temperature and interface temperature between the corium and the concrete were included in the key variables. The concrete ablation temperature must be defined well to define the exact concrete decomposition enthalpy. In addition, as the value of the heat source changed, the effect on the ablated concrete volume was noticeably high.

Next, the derived parameters were converted to the input values in the MELCOR code. The affecting ranges of the values were estimated as shown in Figs. 4 and 5. Above all, it was estimated that the interface between a corium pool and ablated concrete had to be exactly modeled with a crust, gas layer, and concrete slag. In addition, when a stable crust is formed between a corium pool and concrete, the heat transfer is limited on the heat transfer inside a solid crust. The thermal conductivity of oxide mixture had greatly influenced the change of the ablated concrete volume.

This approach had a limitation that heat transfer coefficient was assumed to be constant in the parametric analysis. It concludes the ranges of the effects of the main variables in the MCCI simulation. The ranges of the results from the different models for one resulting value were confirmed.

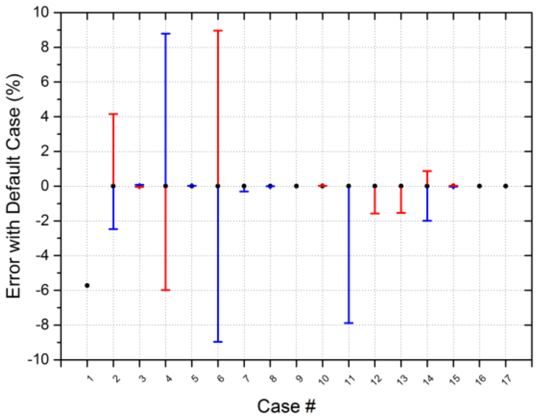

Fig. 4. Change of ablated concrete volume in CCI-2

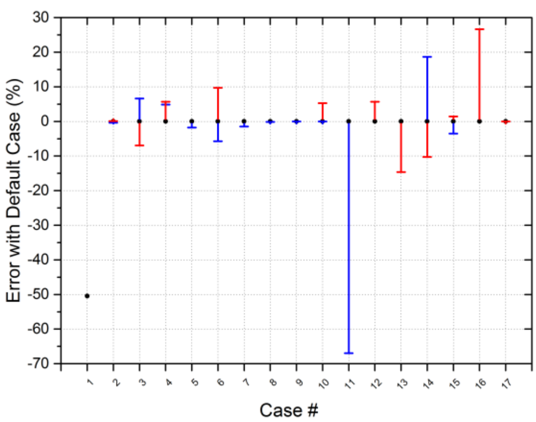

Fig. 5. Change of heat flux to the top water in CCI-2

Acknowledgement

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[1] J.J. Foit et al., The WECHSL-Mod3 Code: A computer program for the interaction of a core melt with concrete including the long term behavior, FZKA 5522, 1995.
[2] USNRC, MELCOR Computer Code Manuals Vol. 1: Primer and Users' Guide, Sandia National Laboratories, SAND2017-0455 O, January 2017.