Comparison of a Corium and Zirconia Melting in the Cold Crucible by CCEMTFA

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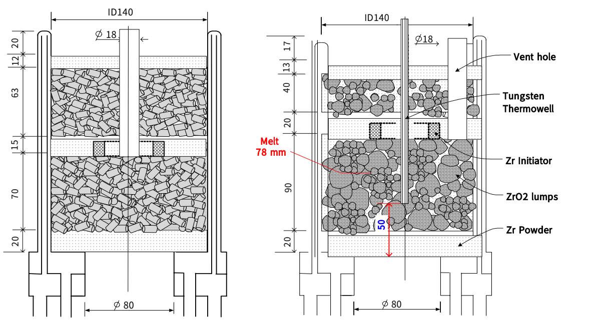
1. Introduction

To evaluate the severe accident effects in a nuclear reactor, an analysis of corium, which is the molten material in a reactor, mainly UO_2 and ZrO_2 including iron and so on, is simulated by using the UO_2/ZrO_2 at a weight ratio of 78/22. The zirconia is also used for a comparison with corium, and it can be treated easily. For the test, the corium and zirconia were melted in the cold crucible and delivered into the water to study the steam explosion effects. An understanding of the melting phenomena and operation conditions of the cold crucible are very difficult, because of the environment of the nuclear material treatment, high frequency induction heating and high pressure conditions in the case of a steam explosion[1]. So the CCEMTFA(Cold Crucible Electro-Magnetic and Thermal Field Analysis) code was used to analyze the melting phenomena for corium and zirconia[2].

2. Experimental Conditions and Results

Corium at a 78/22 weight percent of UO_2/ZrO_2 was used, and the UO_2 was in a pellet form as shown in Fig. 1a. Zirconia was used as powder and lumps that were recovered from the previous experiments in order to increase the charged density as shown in Fig. 1b. The total charged weight was 17.52 kg and 9.0 kg, and the charged density was 6.504 and 3.285 504 g/cm^3, respectively, for the corium and zirconia.



(a) Corium (b) Zirconia

Fig. 1 Charging Patterns

The initial measuring time of the corium temperature was 1190 sec after a heating due to the measuring temperature range(1773~3773 K) of the two color pyrometer. It showed its melting point at 2974 K. As the corium was melted, the melt became a good conductive material from a poor electrical conductive material at a low temperature, and it maintained it to about 3600 K. The corium melt was delivered into the water at 5160 sec and 3630 K[2].

The zirconia melting temperature is also similar to the corium. The melting point of zirconia was shown at 2805 K and the melt temperature was maintained at 3600 K.

3. Code calculation results

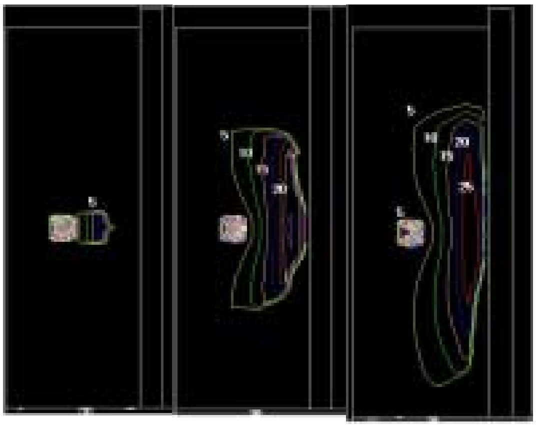
The power was maintained constant at 90 kW in the numerical analysis while the power was carefully controlled for an operational efficiency in the experime nt. Although the power was different, their fundamental characteristics of a cold crucible melting were easily identified and a qualitative comparison was possible.

Table 1 Power Distribution and Electromagnetic force, Heat Generation of Corium and Zirconia(all applied power is 80 kW)

Accu Time sec	Mat'l	Crucible kW	Charge kW	Coil kW	H_{max} W/cm^3	B_{max}, Gauss	Melt	
							T_{avg} °C	Vol. ℓ
60	Cor.	18.76	51.50.	9.74	122	783	0	0
	ZrO_2	18.88.	51.57.	9.55	117	771	0.0	0.0
180	Cor.	55.50.	4.42	20.08	1051	1400	1873	0.02
	ZrO_2	55.40	4.34.	20.26	1068	1410	1947	0.02
300	Cor.	54.79.	5.28	19.93	952	1391	2331	0.02
	ZrO_2	54.72.	5.26	20.02	957	1395	2717	0.02
600	Cor.	54.81	5.281	19.91	949	1391	2719	0.04
	ZrO_2	54.76	5.32	19.93	949	1400	2716	0.09
1800	Cor.	54.70.	5.409	19.89	946	1391	2719	0.11
	ZrO_2	54.53	5.529	19.94	964	1394	2716	0.33
3600	Cor.	53.54	7.005	19.46	927	1373	2735	0.23
	ZrO_2	53.477	6.922	19.60	937	1382	2716	0.68
5400	Cor.	48.46	13.82	17.72	859	1317	2850	1.01
	ZrO_2	49.97	11.79	18.24	872	1361	2717	1.28
7200	Cor.	39.46	26.04	14.51	719	1196	2867	1.74
	ZrO_2	41.75	22.89	15.36	727	1243	2733	1.94
9000	Cor.	32.47	35.47	12.06	593	1105	2883	2.06
	ZrO_2	30.60	38.05	11.35	555	1068	2817	2.14

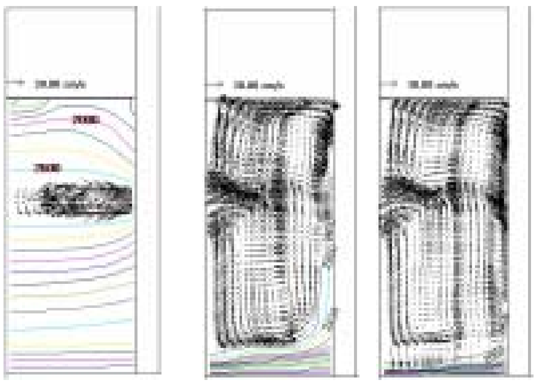
For the applied power of 80 kW, the electromagnetic force and generated power, temperature and melt volume depending on the time and materials are presented in Table 1. The first row can be ignored because the initiator did not ignite in the initial step and its power absorption is too low. Most of the power is lost to the cold crucible itself and coil. The absorbed power into the charge was increased according to the amount of charge which was melted by the combustion heat of zirconium initiator. The maximum absorption power into the charge for corium and zirconia is higher than 35 kW(44 %) after 9000 sec. The melt volume suddenly increases at 600 sec and at 1800 sec for corium and zirconia, respectively.

The heat generation densities are shown in Fig 2, and then the temperature distribution and fluidity are shown in Fig. 3 for corium, and Fig. 4 for zirconia.



a. 1800 sec b. 5400 sec c. 7200 sec

Fig. 2 Generated Powder Density of Corium(contour interval 5 W/cm^3)

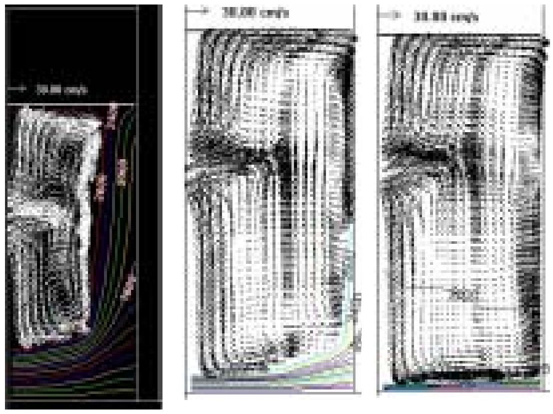


a. 3600 sec b. 7200 sec c. 9000 sec

Fig. 3 Temperature distribution and Fluidity of Corium(80 kW, isothermal line interval 200 ℃)

Though the corium has a higher electrical conductivity than zirconia, their heating speeds were similar in the initial phase owing to their poor conductivity. The electrical conductivity becomes an important role after melting, but the melting volume of zirconia expands more than corium as shown in Figs. 2 and 3. The melt volume of corium and zirconia is 1.01 and 1.28 ℓ, and the average temperature was 2850 and 2717 ^{o}C at 5400 s, respectively. Since the melt density is 7.337 and 5.147 g/cm^3 at these temperatures, the melting mass is 7.4 and 6.5 kg, and then the melt volume percent for the initial charge is 42.3 % and 73.2 % respectively. Although the electrical conductivity of zirconia is lower than corium, zirconia is melted much more owing to the small required input power to melt its small mass and small sensible heat for the given volume.

Though both of the materials are almost melted at 7200 s, they need more overpower for a long time in order to reduce the thickness of the bottom crust for the melt to be delivered into the water. Form this point of view, though zirconia seems easier to deliver, a corium delivery was a little easier than zirconia because corium has a brittle property.



a. 3600 sec b. 7200 sec c. 9000 sec

Fig. 4 Temperature distribution and Fluidity of Zirconia(80 kW, isothermal line interval 200 ℃)

The both of melt temperatures are maintained at about 3600 K in the experiment, while corium was 3156 K and zirconia was 3090 K in the calculation which were a little higher than the melting point. This is because the code is programmed so that the melt temperature is balanced by the curst thickness. That is, if the melt is overheated above the melting temperature, the crust thickness is thinned and the heat loss is increased, and then the melt temperature is decreased. The reverse is the same process. Since the superheated melt is cooled in spite of the power increase at the cooling condition in the experiment, this theory was proven to be a reality.

4. Conclusion

The cold crucible design and operation is very important, because the total input power is lost by about 90 % at the initial phase and 60 % at the end of the melting phase. The supplied heat to the charge is lost at about 26 % through the coolant in the fingers and a very small heat was required to maintain the heat balance during the melting. The zirconia is melted a little earlier than corium in spite of its low electrical conductivity, which has a small amount of charged material. The melt temperature in the experiment is 500 K higher than the analysis. It seems that an air gap exists between the fingers and corium.

ACKNOWLEDGMENTS

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REFERENCES

[1] H. D. Kim, J. H. Song, et. al, “Experimental and Analytical Research on Severe Accident Phenomena; Research on the Containment Risk Assessment,” KAERI/RR-2227/2001, (2001).

[2] H. D. Kim, J. H. Song, et. al., KAERI Report 2005(to be presented)