Analysis of Non-Explosive TROI Particles for Debris Bed Coolability Study

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1. Introduction

According to Korean SAMG, reactor cavity is flooded before a break of reactor vessel in case of a severe accident. Molten corium discharged into pre-flooded water is fragmented into fine particles and accumulated on the cavity surface in the form of debris bed. It has been an important safety issue how to secure the coolability of debris bed for the mitigation of severe accident. One of the research activities being performed at KAERI to resolve this issue is the two-phase pressure drop test using real corium particles which were collected after TROI tests during several years. PSD (Particle Size Distribution), porosity, and effective diameter of the particles are major parameters in the analysis of two-phase pressure drop test. As a first step, non-explosive TROI particles were sieved and analyzed to get the major parameters, which is presented in this paper.

2. Methods and Results

2.1 Sieving and PSD of non-explosive TROI particles

Among many TROI tests where steam explosion did not occur, non-explosive particles obtained from the Tests #1 ~ #4 are chosen for debris coolability study because they are well preserved in the containers. For Tests #1 and #2, free fall is about 1m. For Tests #3 and #4, free fall is about 0m. For Tests #1, #2 and #4, mass ration of UO_2 to ZrO_2 is 70:30. For Test #3, mass ration of UO_2 to ZrO_2 is 80:20. The particles were sieved to get a PSD. The sieving results are shown in Table 1.

Table 1. Sieving of non-explosive TROI particles

Particle size(mm)	Test #1 (kg)	Test #2 (kg)	Test #3 (kg)	Test #4 (kg)
0~0.2	0.045	0.145	0.24	0.12
0.2~0.3	0.05	0.095	0.275	0.135
0.3~0.425	0.1	0.14	0.445	0.245
0.425~0.5	0.065	0.09	0.29	0.155
0.5~0.71	0.375	0.415	1.055	0.58
0.71~1	0.665	0.65	1.385	0.83
1~2	3.94	3.425	5.97	4.44
2~2.8	2.345	2.16	2.955	2.715
2.8~4	5.06	5.405	4.865	4.34
4~5	1.825	1.92	1.55	1.62
5~6.3	2.06	2.29	1.705	1.82
6.3~8	0.925	0.84	0.745	0.955
8~9.5	0.335	0.215	0.22	0.32
9.5~16	0.33	0.21	0.1	0.3
Total	18.12	18	21.8	18.575

Fig. 1 shows a comparison of PSD for Tests #1 ~ #4, FARO-avg, and TROI-avg. The PSD for Tests #1 ~ #4 lies well between average FARO [1] and average TROI [2], which shows a reasonable result. Note that FARO and TROI tests were performed with real corium.

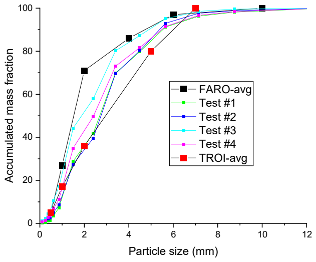

Fig. 1 Comparison of PSD

2.2 Porosity of non-explosive TROI particles

Porosity of the particles was measured for Test #1 using a beaker and a funnel as shown in Fig. 2. Porosity of the particles for the other tests will be measured in the near future. The measurement data will be presented soon.

Fig. 2 Measurement of porosity

2.3 Mean diameter of non-explosive TROI particles

For a packed bed with multi-sized and irregular particles, various mean diameters are applied in the analysis of debris bed coolability. They are mass mean diameter (d_m), area mean diameter (d_a), length mean diameter (d_l) and number mean diameter (d_n), defined as follows:

$$d_m = \sum x_i m_i = \sum \left(x_i \frac{x_i^3 f_i}{\sum x_i^3 f_i} \right) = \frac{\sum x_i^4 f_i}{\sum x_i^3 f_i}$$

$$d_a = \sum x_i a_i = \sum \left(x_i \frac{x_i^2 f_i}{\sum x_i^2 f_i} \right) = \frac{\sum x_i^3 f_i}{\sum x_i^2 f_i}$$

$$d_l = \sum x_i l_i = \sum \left(x_i \frac{x_i f_i}{\sum x_i f_i} \right) = \frac{\sum x_i^2 f_i}{\sum x_i f_i}$$

$$d_n = \sum x_i n_i = \sum \left(x_i \frac{f_i}{\sum f_i} \right)$$

where f_i is the number of particles within the given size range (x_i, $x_i+\Delta x$), and d_m, d_a, d_l, and d_n are size distribution functions by mass, area, length, and number of the particles. Sieving results in Table 1 are used in the calculation. As shown in Table 2, mean diameters for Tests #1 ~ #4 are calculated using the above relations for the whole particle size ranges. Although the mass fraction in the particle size range of 0 ~ 0.2 mm is very small, f_i in this size range is extremely large. This means that particles in the small size range can play a major role in the calculations. As shown in Table 3, mean diameters are also calculated excluding minimum particle size in the range of 0 ~ 0.2 mm. At this moment, it is recommendable to use the mean diameters in Table 3 in the analysis of two-phase pressure drop test. Based on a literature survey [4-7], the effective diameter seems to be between number mean and length mean diameters for multi-sized and irregular particles such as non-explosive TROI particles because of an increased fluid-particle drag. The effective diameter can be obtained using Ergun correlation [8] and data of two-phase pressure drop test in the future.

Table 2 Mean diameter including all particles

Mean diameter (mm)	Test #1	Test #2	Test #3	Test #4
Mass mean	3.49	3.43	2.75	3.24
Area mean	2.13	1.87	1.35	1.7
Length mean	0.77	0.44	0.38	0.49
Number mean	0.2	0.14	0.15	0.16

Table 3 Mean diameter excluding minimum particle size (0~0.2 mm)

Mean diameter (mm)	Test #1	Test #2	Test #3	Test #4
Mass mean	3.5	3.46	2.78	3.26
Area mean	2.24	2.19	1.57	1.9
Length mean	1.23	1.08	0.78	0.93
Number mean	0.64	0.53	0.45	0.5

2.4 Rosin-Rammler distribution of non-explosive TROI particles

For many irregular particles, the mass distribution is found to follow Rosin-Rammler distribution.

$$ln\left[ln\left(\frac{1}{1-F}\right)\right] = n\ln(x) - n\ln(x_0)$$

F: cumulative weight fraction less than size x
n: uniformity constant
x: particle size
x_0: characteristic particle size

Rosin-Rammler distribution is obtained using the sieving results in Table 1 for the cases of including all particles and excluding minimum particle size (0~0.2 mm). Figs. 3 and 4 show the linearized Rosin-Rammler distribution.

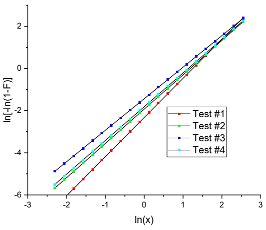

Fig. 3 Rosin-Rammler distribution including all particles

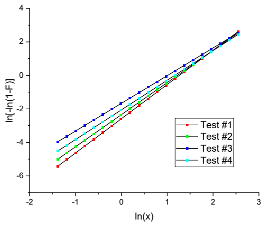

Fig. 4 Rosin-Rammler distribution excluding minimum particle size (0~0.2 mm)

Table 4 shows the uniformity constant (n) and the characteristic particle size (x_0). The uniformity constant (n) is in the range of 1.50 ~ 2.05, which is similar to other test data (FARO, PREMIX, and GPX) [3]. It is noted that the characteristic particle size (x_0) is almost the same as the mass mean diameter for the case of excluding minimum particle size (0~0.2 mm).

Table 4 Uniformity constant (n) and characteristic particle size (x_0)

		Test #1	Test #2	Test #3	Test #4
Including all particles	n	1.86	1.63	1.5	1.6
	x_0 (mm)	3.5	3.27	2.61	3.1
Excluding minimum particle size	n	2.05	1.92	1.65	1.77
	x_0 (mm)	3.55	3.4	2.74	3.2

3. Conclusions

Coolability of debris bed in wet cavity is of great safety issue for the mitigation of severe accident. For the resolution of this issue, two-phase pressure drop test using non-explosive TROI particles is planned at KAERI. As a first step, an analysis of particles is conducted to get the information of PSD, porosity, and mean diameters. The information is used for future study.

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