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Simulation on the Statistical Analysis of the Distribution of Coated Particles in a 3-Dimensional Cylindrical Compact

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1. Introduction

A pebble-type fuel compact or a cylindrical compact can be used in high temperature gas-cooled reactor design[1]. Fuel compact has TRISO-coated particles dispersed in graphite matrix. The coated particles should be distributed as homogeneously as possible in a compact. The homogeneity of coated particles in a fuel compact can be analyzed from the cross-section image or from the 3-dimensional space of the compact[2, 3]. In this study, the homogeneity of coated particles has been statistically analyzed from a virtual 3-dimensional space of a cylindrical compact.

2. Homogeneity of Particles in a Compact

TRISO-coated fuel particle is composed of a kernel and coating layers. The density of a kernel is much higher than that of the coating layers or than that of the graphite matrix in a compact. Hence, the fuel particles can be distinguished nondestructively by the density difference in the from a cross-section image such as an x-ray tomographic image. A 3-dimensional space can be constructed with the cross-section images for a compact. The volume size of particles can be measured in a 3-dimensional sphere with a defined radius. It is expected that the mean of the volume is constant, so the standard deviation is small if the particle distribution is homogeneous as in a 2-dimensional image[3]. The homogeneity of a particle distribution can be evaluated by the mean and standard deviations of the particle volume in a 3-dimensional space as shown in Fig. 1.

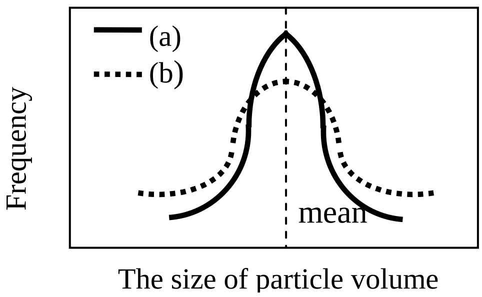

Fig.1. A homogeneous distribution(a) and a non-homogeneous distribution(b) of particle volume in a compact.

The mean value is calculated by equation (1). The standard deviation is calculated by equation (2).

$$m_p = \frac{1}{N}\sum_{i=1}^{N} P_i \quad , \tag{1}$$

$$V_p = s_p^2 = \frac{1}{N}\sum_{i=1}^{N}(P_i - m_p)^2 \tag{2}$$

where, m_p is the mean of the volume of the particle area, N is the number of sampled spheres, P_i is the volume of a particle area in the i-th sampled sphere. V_p is the variance, and s_p is the standard deviation.

3. Simulation parameters

Table 1 shows the simulation parameters to analyze the homogeneity of the coated particles in a 3-dimensional space of a compact. Particles were arranged on the vertex of a regular tetrahedron in a compact to maintain a complete homogeneity as shown in Fig. 2 (a). Where, the distance between neighboring particles is the same. The distance is not constant for a non-homogeneous distribution as shown in Fig. 2 (b).

Table 1. Simulation parameters.

Compact diameter	12 mm	256 pixels
Compact length	25 mm	533 pixels
Coated particle diameter	937.5 μ m	20 pixels
Kernel diameter	562.5 μ m	12 pixels
Packing fraction	20.8 %	
Number of particles	1364 ea in a compact	
Distance between neighboring particles	1359.4 μ m	29 pixels

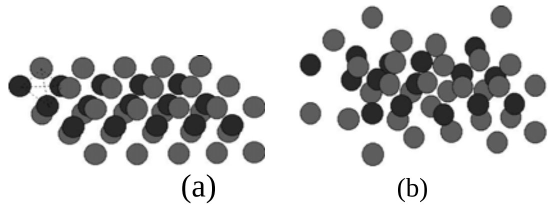

Fig.2. (a) A homogeneous distribution of particles in a compact and (b) a non-homogeneous distribution of particles in a compact.

4. Result of Experiment

In the experiment, the radius of a sampled sphere was varied from 10 to 100 with a step of 10 pixels.

The variation of the standard deviation was settled less than 2 % over 1200 samples in the 2-dimensional simulation[3]. The sample number was also optimized as 1200 in this simulation.

The size of a sampled sphere is defined by the radius of a sphere. If the radius is too small, the standard deviation is large for all kinds of distributions. If the radius is too large, the standard deviation is small for all kinds of distributions. It is difficult to tell a homogeneous distribution from a non-homogeneous distribution in the case of both of them. The optimized radius should be determined to discriminate a homogeneous level. The variation of the standard deviation over the mean of the sizes of the particle areas was measured for the homogeneous and for the non-homogeneous distribution for a sample number of 1200 for a radius range as shown in Fig. 3. The non-homogeneous distribution was modeled by adjusting the distance between the particles based on the non-homogeneous distribution. The homogeneous level could be clearly discriminated for the radii of between 20 and 60.

The ratio of the standard deviation over the mean value for a tested image was measured for a radius of 20, 30, 40, 50 and 60. The difference between the parameters for the standard distribution and those of the tested distribution was integrated for a radius of 20, 30, 40, 50 and 60. The smaller the difference parameter is, the more homogeneous the distribution of the particles in a compact is. The homogeneity of 3-dimensional distribution(HL_3) is calculated by equation (3).

$$HL_3 = \sqrt{\frac{1}{5}\sum_r (T_r - B_r)^2}\ , \qquad (3)$$

$$T_r = \frac{st_r}{mt_r}\ ,\quad B_r = \frac{sb_r}{mb_r}\ ,$$

$$r = 20,30,40,50,60\ .$$

Where, mt_r is the mean of the sizes of the particle areas for the radius of r for a test, st_r is the standard deviation for a test, mb_r is the mean of the sizes of the particle areas for the radius of r for a standard homogeneous image, and sb_r is the standard deviation for a standard image. The homogeneity level factor, HL_3 , was small in the case of a homogeneous distribution. The homogeneity level factor of the distribution A, B, C, D and E is 0, 1, 5, 10 and 15, respectively in Fig. 3. The 3-dimensional distribution of particles in an arbitrary compact can be evaluated by the homogeneity level factor.

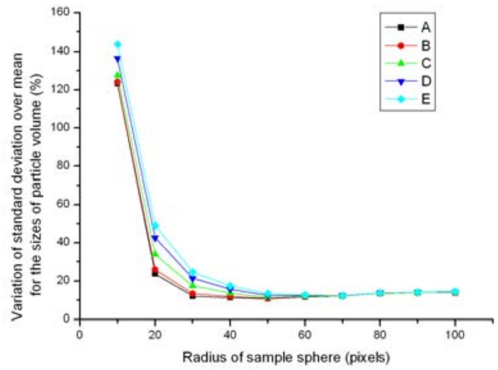

Fig. 3. Variation of the standard deviation over the mean value for the radius of a sampled sphere in a compact.(HL_3 : 0(A), 1(B), 5(C), 10(D), 15(E))

5. Conclusion

In this study, homogeneity level of the particles in a cylindrical compact was analyzed stochastically by a simulation for a virtual 3-dimensional space. The experimental results are as follows.

- The optimum radius of a sampled sphere was acquired by the simulation to evaluate the homogeneity level of the distribution of the particles in a cylindrical compact.
- The homogeneity level of the tested distributions could be evaluated in a 3-dimensional space based on a standard homogeneous distribution.

Acknowledgement

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REFERENCES

[1] M. S. Cho, etc., “HTGR Fuel Compact Fabrication Technology,” KAERI/AR-759/2006, pp.1-4, 2006.
[2] D. Tisseur, J. Banchet, P. Duny, M. Mahe and M. Vitali, “Quality Control of High Temperature Reactors(HTR) Compacts via X-ray Tomography,” Proceedings of HTR2006, 2006.
[3] W. K. Kim, etc., “Simulation on the Statistical Analysis of the Distribution of Coated Particles on a Virtual Tomograph in a Cylindrical Compact,” Transaction of the KNS Spring Meeting, 2008.