Simulation on the Statistical Analysis of the Distribution of Coated Particles on the Virtual Tomograph in a Cylindrical Compact

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1. Introduction

Two types of fuel compacts are currently used in high temperature gas-cooled reactor design. The one is a pebble-type fuel compact which is a sphere with a diameter of about 60 mm for a pebble bed reactor. The other is a block-type fuel element which is a cylindrical form with a diameter of about 12 mm and a length of about 50 mm for a prismatic block modular reactor[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 compact can be analyzed from the cross-section image of the compact.[2] In this study, the homogeneity of coated particles has been statistically analyzed from a virtual cross-section image 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 due to the difference in the density from a cross-section image such as an x-ray tomographic image. The two dimensional particle area can be measured in a circle area with a defined radius. It is expected that the mean of a size is constant, so the standard deviation is small if the particle distribution is homogeneous. The homogeneity of a particle distribution can be evaluated by the mean and standard deviations of the sizes of the particle areas as shown in Fig. 1.

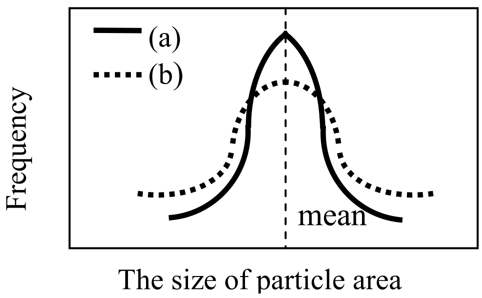


Fig.1. A homogeneous distribution(a) and a non-homogeneous distribution(b) of particle area in a compact.

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

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

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

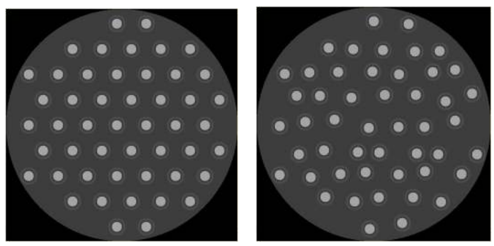
where, m_p is the mean of the sizes of the particle areas, N is the number of sampled circles, P_i is the size of a particle area in the i-th sampled circle. V_p is the variance, and s_p is the standard deviation.

3. Simulation parameters

Table 1 shows the parameters in the simulation to analyze the homogeneity of the coated particles in a compact. Particles were arranged on the vertex of a regular triangle for the cross-section image of 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 image as shown in Fig. 2 (b).

Table 1. Simulation parameters.

Compact diameter	12 mm	512 pixels
Coated particle diameter	937.5 μ m	40 pixels
Kernel diameter	515.6 μ m	22 pixels
Packing fraction	20 %	
Number of particles	49 ea on an cross section	
Distance between neighboring particles	1523.4 μ m	65 pixels



(a) (b)

Fig.2. A homogeneous distribution image(a) and a non-homogeneous distribution image(b) of particles on the cross-section in a compact.

4. Result of Experiment

In the experiment, the radius of a sampled circle was varied from 20 to 200 with a step of 20 pixels. The number of samples was varied from 200 to 2000 with a step of 200.

If the number of samples is too small, the statistical data is not reliable. A lot of data processing time is required in the case of a large sample number. So, the number of sampled circles should be optimized. To determine the optimum sample number, standard deviations for the sizes of the particle areas were measured 10 times based on radius parameters. The variation of the standard deviation was measured by the ratio of the standard deviation(STD) over the average(AVG) of the standard deviations(SD) through 10 trials for the given radius of a sampled circle and the sample number.

The variation of the SD was measured for a standard cross-section image as shown in Fig. 2(a). The variation of the SD was settled less than 2 % over 1200 of a sample number as shown in Fig. 3. The sample number was optimized as 1200.

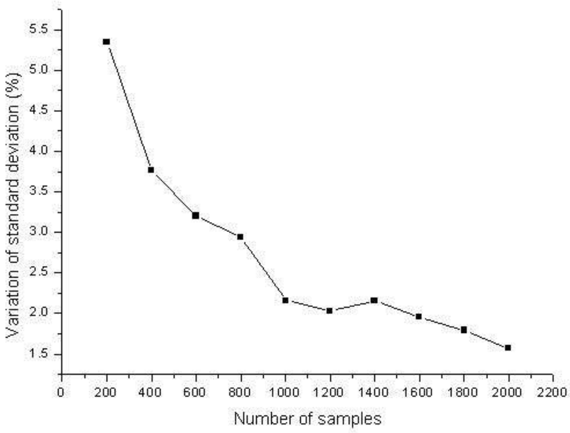


Fig. 3. Variation of the standard deviations through 10 trials.

The size of a sampled area is defined by the radius of a circle area. 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 images for a sample number of 1200 over a radius range as shown in Fig. 4. The homogeneous level could be cleary discriminated for the radii of between 40 and 140.

The ratio of the standard deviation over the mean value for a tested image was measured for a radius of 40, 60, 80, 100, 120, and 140. The sample number is fixed as 1200. The difference between the parameters for the standard image and those of the tested image was integrated for a radius of 40, 60, 80, 100, 120, and 140. The smaller the difference parameter is, the more homogeneous the distribution of the particles in a compact is. The homogeneity(HL) is calculated by equation (3).

$$HL = \sqrt{\frac{1}{6}\sum_r (T_r - B_r)^2}\,, \qquad (3)$$

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

$$r = 40, 60, 80, 100, 120, 140.$$

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, HL, was small in the case of a homogeneous distribution.

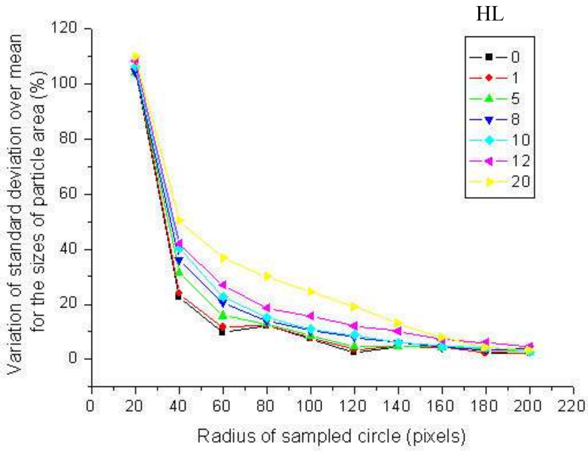


Fig. 4. Variation of the standard deviation over the mean value for the radius of a sampled circle.

5. Conclusion

In this study, homogeneity level of the particles in a cylindrical compact was analyzed stochastically by a simulation for a virtual cross-section image such as a tomographic image. The experimental results are as follows.

- The optimum number of sampled circles as well as the optimum radius of a sampled circle was acquired by the simulation.
- The homogeneity level of the tested images could be evaluated based on a standard homogeneous image.

Acknowledgement

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