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A Proposal on the Quantitative Homogeneity Analysis Method of SEM Images for Material Inspections

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1. Introduction

A scanning electron microscope (SEM) is a method to inspect the surface microstructure of materials. The SEM uses electron beams for imaging high magnifications of material surfaces; therefore, various chemical analyses can be performed from the SEM images. Therefore, it is widely used for the material inspection, chemical characteristic analysis, and biological analysis.

For the nuclear criticality analysis field, it is an important parameter to check the homogeneity of the compound material for using it in the nuclear system. In our previous study [1], the SEM was tried to use for the homogeneity analysis of the materials. However, as shown in the previous studies [2-4], the material property using SEM images have been only studied as the qualitative analysis, not quantitative analysis. In this study, with a development of the image analysis program, a method to analyze the quantitative homogeneity is proposed using the concepts on the relative standard deviation (*RSD*) and normal distribution test.

2. Methods and Results

2.1 Proposal of the Homogeneity Estimation Method

To estimate the homogeneity in this study, a SEM image is converted to the bitmap format. The bitmap image is a method to store an image to the binary type in each pixel. Therefore, each pixel includes color depth of 1, 4, 8, 16, 24, 32, 48, or 64 bits. Also, the pixel has the grayscale to express the brightness. For the homogeneity analysis of the SEM image, a program to read the grayscale is developed using C++ program language in this study.

It is clear that the brightness is different for each SEM image. Also, the homogeneity of the image cannot be analyzed by the single brightness of the pixel. Here, we introduce the group-wise analysis strategy for the homogeneity analysis. First, the brightness is counted for the red, blue and green color depths in each pixel. Then, the brightness is averaged for the three colors. After reading the bitmap file, the average brightness is calculated by Eq. (1).

$$A[i,j]=\frac{\sum_{j=1}^{m}\sum_{i=1}^{n}(R[i,j]+B[i,j]+G[i,j])/3}{n\times m} \quad (1)$$

where i is the row, j is the line, $R[i,j]$, $B[i,j]$ and $G[i,j]$ are the brightness of the red, blue and green colors at i^{th} row and j^{th} line pixel, and n and m is the numbers of the row and line, respectively. Before to count the number of the pixels, the pixel brightness $BR[i,j]$ is digitally converted using Eq. (2).

$$\begin{cases} if\ \frac{R[i,j]+B[i,j]+G[i,j]}{3} > \mathrm{A}[i,j]\ , & BR[i,j]=1 \\ \text{otherwise}, & BR[i,j]=0 \end{cases} \quad (2)$$

The SEM image, which has the n x m pixels, are divided to the groups, and the $BR[i,j]$ are summed for each group as given in Eq. (3).

$$GB[I,J]=\sum_{j}^{m/l}\sum_{i}^{n/r}BR[i,j] \quad (3)$$

where group brightness, $GB[I,J]$, is the sum of the $BR[i,j]$ for I^{th} row and J^{th} line group, and l and r are the numbers of divisions for the row and line for the group-wised SEM image analysis. If a material has a homogeneous distribution, the $GB[I,J]$ distribution of the material has the following properties:

i) The number of the bright pixels is constant for each group. With the stochastic analysis, the *RSD* of $GB[I,J]$ will have a very small value comparing the heterogeneous compositions. The *RSD* can be calculated by Eq. (4).

$$RSD=\frac{S[GB[I,J]]}{E[GB[I,J]]} \quad (4)$$

where $S[GB[I,J]]$ is the standard deviation of $GB[I,J]$ and $E[GB[I,J]]$ is the average of $GB[I,J]$.

ii) The number of the pixels in the group is not infinite; therefore, in the homogeneous material, the number distribution of $GB[I,J]$ groups as the number of the bright pixels follows a normal distribution. However, for the heterogeneous composition of the material, it follows the other distribution. Using the property, Jarque-Beta test [5], which was developed for the test of the normal distribution, is performed to judge the homogeneity. The test statistic Jarque-Beta (*JB*) is defined as Eq. (5). From the *JB* test, the *p*-value can be obtained using approximation of the chi-squared distribution from the data table [6].

$$JB = \frac{n}{6}\left(S^2 + \frac{1}{4}(K-3)^2 \right) \qquad (5)$$

where, n= number of groups

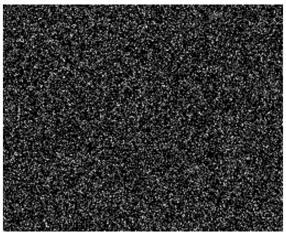
$$S = \frac{\sum_I \sum_J (GB[I,J] - E[GB[I,J]])^3 / n}{S[GB[I,J]]^3}$$

$$K = \frac{\sum_I \sum_J (GB[I,J] - E[GB[I,J]])^4 / n}{S[GB[I,J]]^4}$$

In this study, the homogeneity is analyzed with the two aspects which are the *RSD* and *JB* normal test. For the *RSD* test in this study, a perfect homogeneity is defined to *RSD* = 0. This means that if the *RSD* is increased, the homogeneity is getting lower. Also, using the *JB* normal test, the *p*-value is over 0.05, it can be diagnosed that the distribution is a homogeneous distribution based on the statistical theory.

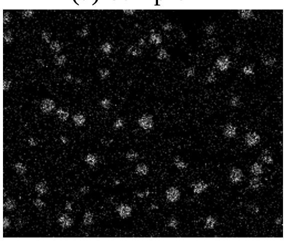
2.2 Evaluation and Analysis

For the verification of the proposed homogeneity diagnostic method, the SEM images estimated in our previous study [1] were selected as shown in Fig. 1. Then, the images were converted to bitmap format. For the evaluation with the proposed method, the image were divided to 10 x 10 groups, and then, the *GB*[*I*,*J*] was counted using Eq. (3) for each group. Fig. 2 shows the number of the groups as the *GB*[*I*,*J*] counts.

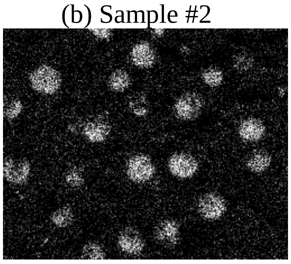


(a) Sample #1

(b) Sample #2

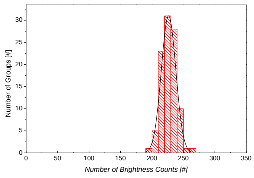


(c) Sample #3

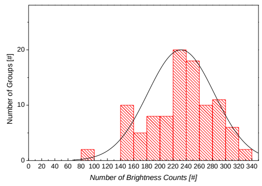


(d) Sample #4

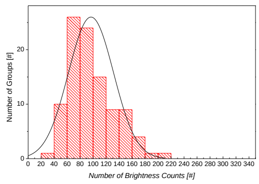
Fig. 1. Samples of SEM Images for the Homogeneity Tests



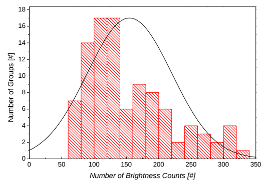
(a) Sample #1



(b) Sample #2



(c) Sample #3



(d) Sample #4

Fig. 2. Number of Groups as the Number of *GB* Counts

Using the *GB*[*I*,*J*] data for each sample, the *RSD*s and *p*-values were evaluated. The results are given in Table I. In visual inspection, it can be judged that the homogeneities of the materials are as follows:

Sample #1 > Sample #2 > Sample #3 > Sample #4

However, it cannot express the quantitative homogeneity using these qualitative analyses. Using the method proposed in this study, following diagnostics on the homogeneity can be deduced:

1) Samples #1 and #2 are homogeneous based on the *JB* normal test; however, the homogeneity of Sample #1 based on the *RSD* is higher about 4 times than that of Sample 2.
2) Samples #3 and #4 are heterogeneous based on the *JB* normal test; however, the homogeneity of Sample #3 based on the *RSD* is higher about 1.2 times than that of Sample 4.

Analysis shows that the quantitative homogeneity can be analyzed using the proposed method while the qualitative analysis has been only pursued in the previous studies.

Table I: Results of the Homogeneity Analysis

	Sample #1	Sample #2	Sample #3	Sample #4
RSD	0.05064	0.21758	0.35724	0.42087
p-value	0.5000	0.1028	0.0092	0.0072
Homo. (p>0.05)	True	True	False	False

3. Conclusions

In this study, a quantitative homogeneity analysis method of SEM images is proposed for the material inspections. The method is based on the stochastic analysis method with the information of the grayscales of the SEM images. First, the SEM images are divided to the group with a uniform mesh; and then, the pixels are counted in which the pixel exceeds the average brightness. Using the counted number in each group, two kinds of statistical analyses, *RSD* and *JB* test, are performed. After analyzing the *RSD* and *JB* tests, the homogeneity is quantitated. For the verification, the homogeneity tests were pursued with the proposed method. The analysis results show that the proposed method can effectively quantitate the homogeneities of the SEM images. It is expected that the proposed method can be directly utilized for the material inspections, which requires homogeneity analysis of the nuclear materials.

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