Quantitative analysis on micro-fluctuation of several bowls by scanning laser microscope

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Relaxation, fluctuation and surface irregularities of a famous potter's bowl and other objects were evaluated with an analytical procedure developed by applying fractal concepts and the Richardson effect. Important results of this study can be summarized as follows. (1) An analytical system using a scanning laser microscope system was developed to evaluate the irregular surface of fluctuations quantitatively; an analytical procedure to develop the Mesh method was established. (2) Irregular surfaces in micro areas of the analyzed objects have a fractal nature: (a) the famous potter's bowl, (b) the original handmade bowl, (c) the original handmade coffee cup, and (d) the Black teacup. (3) The famous potter's bowl has a fractal nature and relative self-similarity over wide analytical ranges. (4) Fractal dimensions and the nature of relaxation were connected as D=2.40. This value is useful for application to the design of a mechanical structure in later studies.

(Received November 20, 2008; accepted January 21, 2009)

Keywords: Fractal, Laser-aided diagnostics, Shape measurement, Image processing, Surface roughness, Fractal dimension, Richardson effect, Geometrical irregularity, Relaxation, Transcription

1. Introduction

In modern social life, which is flooded with exhaustion and stress, the term "healing" is coming to the forefront of discussion. A typical example of healing is 1/f fluctuation, which is used commercially in wind control of electrical fans. A wide variety of healing modes exist, such as music, patterns, and shapes. Humans are comforted because both alpha brain waves and 1/f wavelengths have a similar biological rhythm. If quantitative aspects of healing components are investigated thoroughly, a certain index required for transferring healing can be well defined. Through such means, establishment of technology that transfers healing components from one object to another can be approached. Transferred healing has comparable healing effects to those of the original object, but destination objects might have entirely different geometries. That is, the destination object is not an imitation or pastiche; rather, it imparts a peculiar healing effect. Application of this transfer technology can provide original extra value for surfaces of die forging or machinery structures currently manufactured in a mass-production line. This technology, once established, is limitlessly applicable, from machinery members to livingware. As a result, it will contribute to supplying relaxation effects to modern society.

The authors have applied fractal geometry, combined fractal dimension D and a surface property index relevant to Richardson effect [1] to conduct quantitative analyses of irregular unevenness with various irregular surface properties [2-5]. The present analysis is characterized by performing fractal analysis not of the linear uneven profile of the irregular shape but the irregular surface itself as the object. Application of quantitative analysis using fractal dimensions has been carried out and reported in surface geometry analysis of various analysis objects such as metallic materials [6-15], ceramics [16], FRP [17], and rocks [18-19]. However, such works have mostly analyzed the irregular properties of a line. Including the authors', these studies concern only the quantitative evaluation of various irregular shapes using fractals; no such quantitative data have been used in later design or machining. That is, aside from very few reports [20], there has been no study in which fractal dimensions are applied to the design of structural members as a certain index because it is difficult to discern a correlation between various parameters including fractal dimensions obtained by fractal analysis and physical quantities in an object to be designed.

Against such a background, this study addresses fractal analysis of the surface properties of a bowl by a famous potter: a masterpiece of healing. Our ultimate goal is to establish technology that transfers this fluctuation to die-forged surfaces or machined surfaces. In the previous report [21], the authors conducted fractal analysis of macroscopic visual healing according to surface properties of various bowls, thereby verifying that the surface properties of each bowl can be represented using fractals. Moreover, it was demonstrated that the combination of fractal analysis and FFT analysis can express the fluctuation and healing of the surface properties of a famous potter's bowl as a fractal dimension of D=2.33.

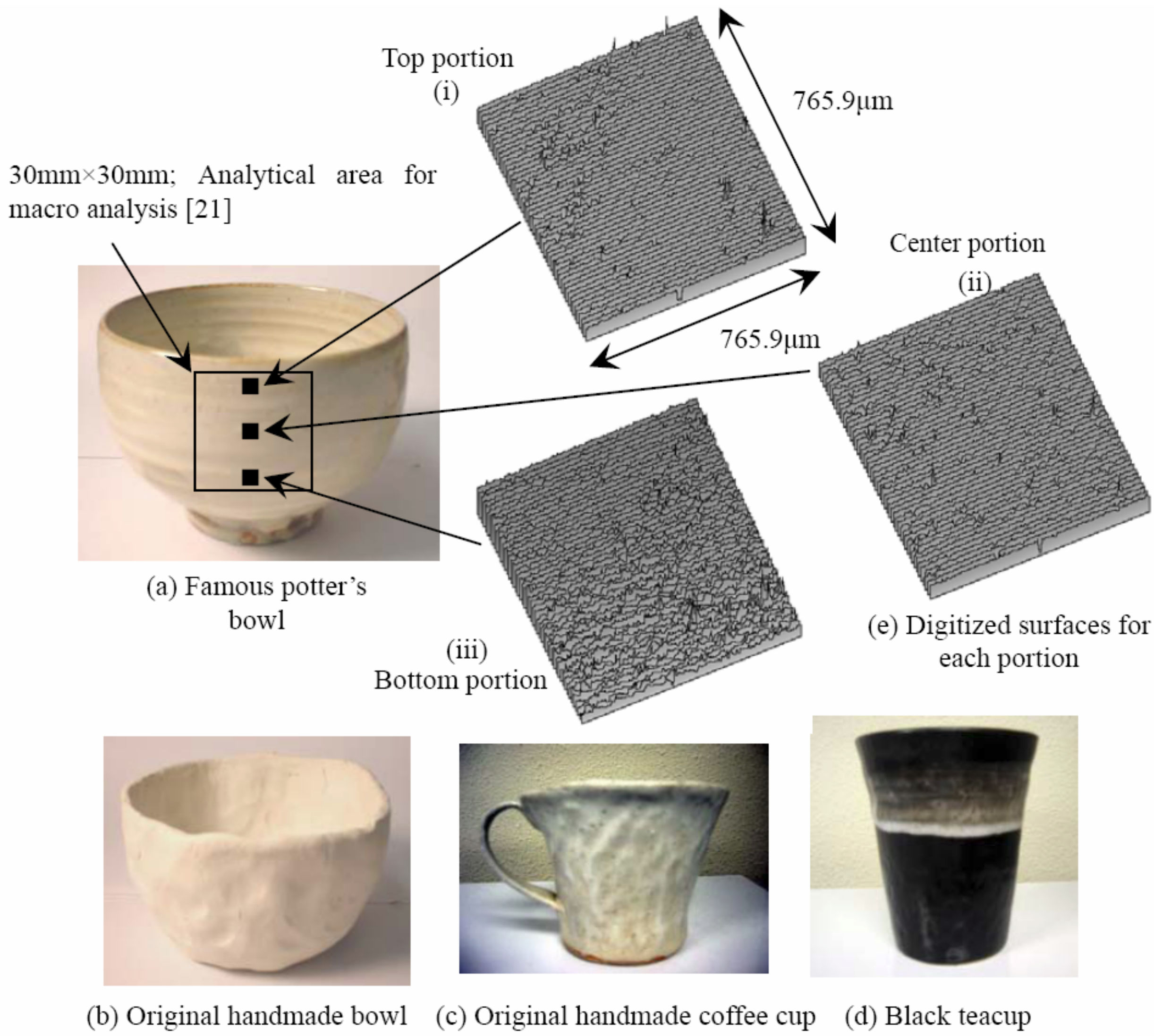

Fig. 1. Photographs of analysis object and digitized surfaces.

This report, as the second stage, concerns fractal analysis of quantitative data using a scanning laser microscope to assess microscopic surface properties of the same bowls used in the first report. This study is intended to define a transfer index towards transfer technology establishment that will be reported in our future reports, by combining microscopic data obtained here with macroscopic data in the first report. Furthermore, self-similarity [22-23], a characteristic of fractals, is also verified.

2. Analysis object

The present analysis targeted four types of vessels used in the first report, including one by a famous potter, all having various qualities of unevenness. Among these, the famous potter's bowl is shown in Fig. 1 (a); some call it healing, chic, or having warmth of affection. Fig. 1 (b), 1 (c), and 1 (d) respectively depict the objects for comparison: an original handmade bowl, an original handmade coffee cup, and a black teacup. The positioning of each object for comparison to the famous potter's bowl should be referred from the preceding report.

The macroscopic region was defined in the previous report [21] as a 30mm×30mm square area, where visual healing effects were evaluated by visual observation. This study defines the microscopic region as an area of less than 1mm square, e.g., 384.1μm×384.1μm (×500) or 765.9μm×765.9μm (×250). In a microscopic region, healing is imparted by the tactile sense via fingertips as an evaluator touches an object. Continuous analyses of surface properties on regions of different scales of analysis will provide quantitative data that express important parameters of macroscopic and microscopic healing. These data will act as an index for future transfer machining, which will be reported in future reports. In addition, verifying self-similarity, one characteristic parameter of fractals is expected to connect healing and fractal geometry physically.

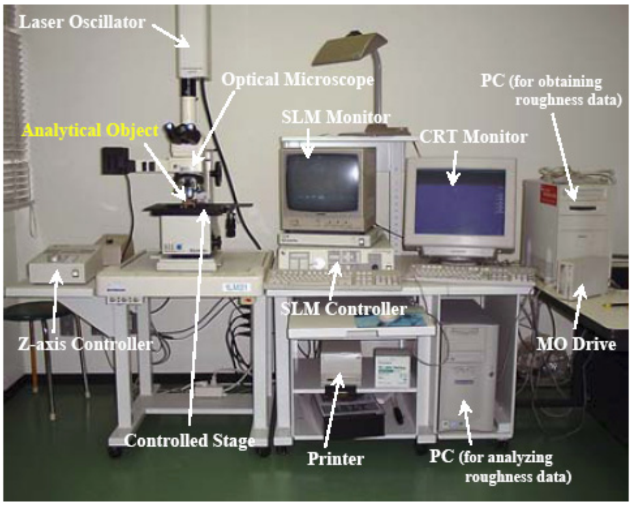

Fig. 2. Whole view of scanning laser microscope system.

This study defines three microscopic regions as analysis regions, as shown in Fig. 1 (a): the upper, middle, and lower parts of the interior of a 30mm×30mm rectangular region defined as a macroscopic region in the first report. These regions for analyses are named as (i), (ii), and (iii) sequentially from the top. The below-mentioned fractal analyses were conducted for these microscopic regions.

3. Surface properties observation by scanning laser microscope

This study employs a scanning laser microscope (SLM, 1LM21; Lasertec Corp.) for observation of surface properties of analysis objects. The scanning laser microscope is characterized by the fact that quantitative 3-D information is obtainable on a real-time basis, which cannot be done using a scanning electron microscope (SEM) used in general fractography. Furthermore, SLM is advantageous in that it allows observations in air at nonconducting conditions. Moreover, it has little thermal effect on the object. For those reasons, SLM is considered to be optimal for observation procedures for art works and expensive items like those used in this study because it causes only slight material damage to an analysis object. Especially the point that 3-D information is obtained quantitatively is of great convenience for the below-mentioned fractal analysis.

The overview of SLM is illustrated in Fig. 2. Laser light discharged from the laser light source irradiates the surface of the bowl used for analysis, which has been placed on the sample base of the optical microscope. The state of unevenness of this bowl's surface is expressed as a monochrome shaded image on the SLM monitor. Shaded areas of the SLM image represent unevenness; bright and dark areas correspond respectively to mountains and valleys. The SLM device employed in this study converts elevation differences in the scanned area into 8-bit (256 levels) monochrome contrast and creates an image on the monitoring screen. Then, this SLM image is sent on-line and saved into the computer, inverted to numerical elevation data, and employed for fractal analysis of surface properties.

Fractal analysis of surface properties is conducted for the microscopic analysis regions: 384.1μm×384.1μm and 765.9μm×765.9μm. These analysis regions are determined from observation results of display images at respective magnifications of ×500 and ×250 on the SLM monitor. The actual physical regions of images recorded at these magnifications cover 614.5μm×460.9μm (×500), and 1125.5μm×919.1μm (×250). These regions correspond to a rectangular region of 320dot×240dot as a LCD image. This analysis defines square regions of 200dot×200dot, i.e., 384.1μm×384.1μm (×500), and 765.9μm×765.9μm (×250) as analysis regions among the full-scale images on the LCD. Accordingly, 1pixel on the LCD corresponds to about a 1.9μm×1.9μm (×500 magnification) and 3.8μm×3.8μm physical areas on pottery surfaces.

As an example of SLM observation, based on evaluation data obtained by SLM at ×250, unevenness was displayed in 3-D using Scion Image 4.02 (freeware by Scion Corp.). Surface properties are reproduced into Fig. 1 (e), where slightly greater unevenness is observed at the lower part of analysis region (iii).

4. Fractal analysis procedure of healing surface properties

The authors have extended the Mesh method [2-4] and Yardstick method [5], studied fractal analysis results for various surface properties of metal surfaces, and reported that this analysis method enables good quantitative evaluation of surface properties of various metals. This analysis method is therefore expected to be sufficiently applicable also to quantitative evaluation about healing transfer technology establishment.

To assure consistency with fractal analysis of macroscopic regions undertaken in the previous report, this study adapts the same analytical procedure and analytical method as in the previous report for quantitative analysis of microscopic fractal properties. Quantitative analysis with an identical analysis procedure facilitates a direct comparison between macroscopic fractal dimension data obtained in the first report and this microscopic fractal dimension. The systematic analysis method used in this study extends Mesh method to a 3-D shape, and computes fractal dimension D from the gradient of a straight line of Richardson effect in Eq. (1):

$$\ln S = \ln F + (2-D) \ln \varepsilon \tag{1}$$

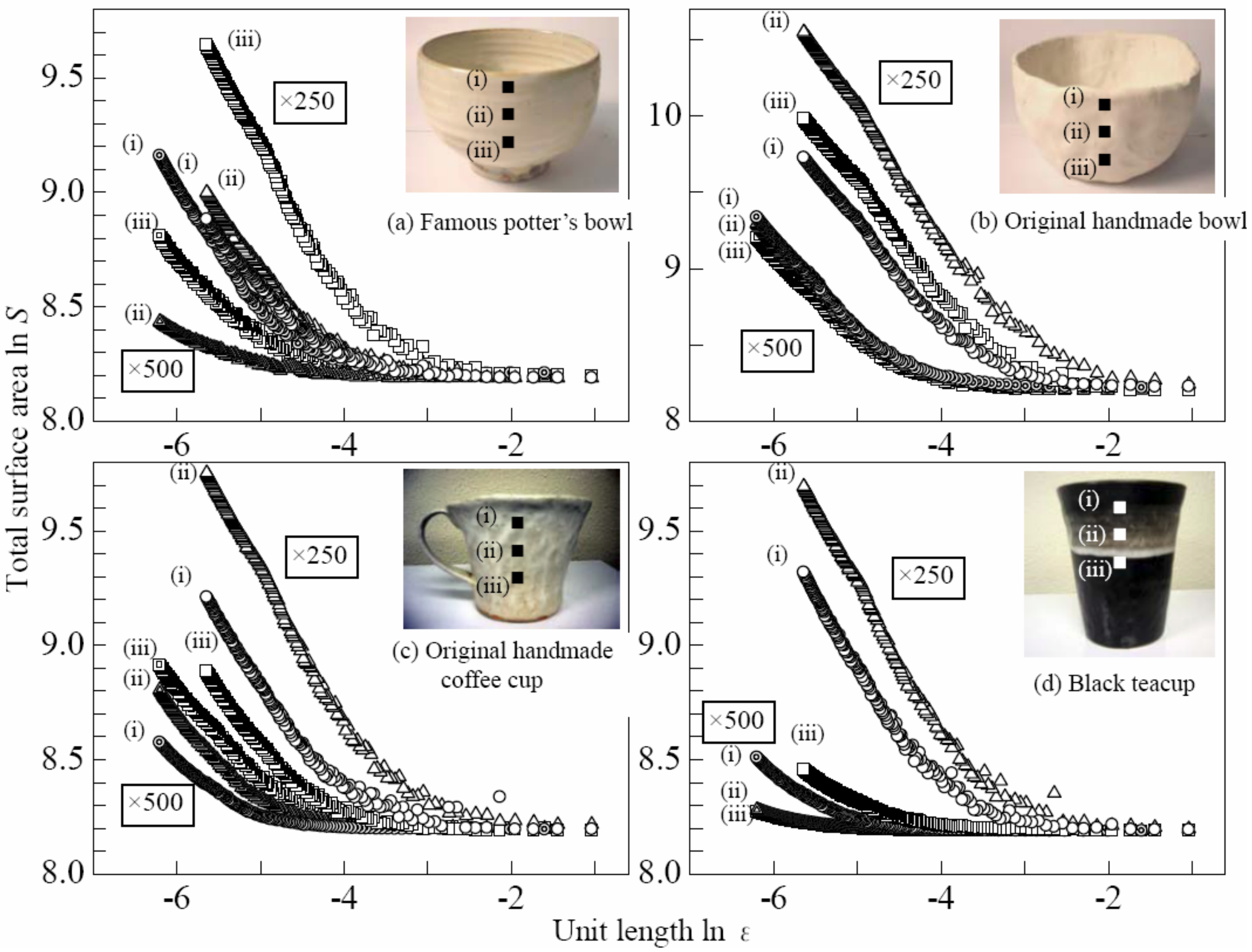

Fig. 3 ln ε-ln S relationships of each analytical object for micro area.

This equation suggests that edge length ε of an edge of the microscopic region on the bowl for analysis and surface area *S* computed from height data based on an SLM image have a downward-sloping linear relationship following the Richardson effect on double logarithmic coordinates. Derivation of Eq. (1), the physical meaning of each index, and the calculation procedure of fractal dimension *D* from the straight line of the Richardson effect should be referred from the previous report.

5. Analysis result and discussion

The ln ε-ln *S* relationships were obtained for microscopic analysis regions on the surface of various bowls shown in Chapter 2 with the above-mentioned analytical procedure, as shown in Fig. 3. The figure indicates a linearly decreasing trend of *S* from the maximum area (the upper-leftmost measuring point) according to increased ε. This suggests that the Richardson effect is observed over the analysis region, and that fractal properties exist. However, the Richardson effect is not observed in the whole range of ln ε, but fractal properties are detected in a region of small ε. Fractal dimension *D* is computable from the gradient of this straight line as Eq. (1). Table 1 summarizes the averages of fractal dimensions computed from the gradient of straight lines following the Richardson effect in Fig. 3.

Table 1 presents fractal dimensions of microscopic regions of the famous potter's bowl (a): *D*=2.57 for the 765.9μm×765.9μm region (×250), and *D*=2.43 for the 384.1μm×384.1μm region (×500). The analysis result for macroscopic regions in the first report is *D*=2.33. Therefore, the relative self-similarity between both regions has been verified. This is clear also in Fig. 4, the plot of self-similarity. In comparison, the respective fractal dimensions *D* of the original handmade bowl (b) and coffee cup (c) are *D*=2.65 and *D*=2.52. Although these values represent tactile healing comparable to that of the famous potter's bowl (a), they differ markedly from the fractal dimensions of macroscopic region. Fig. 4 also supports this tendency. A certain difference exists in the healing extent between visual and tactile senses, implying that the original handmade bowl (b) and coffee cup (c) might not display healing attributes of as wide range as the famous potter's bowl (a). The analysis result for the black teacup (d) shows self-similarity between ×250 and the macroscopic region. However, great difference in the fractal dimensions of microscopic regions between ×250 and ×500 suggests no continuous self-similarity. Therefore, it is inferred that the investigation of fractal dimension *D* and self-similarity reveals a distinction between the famous potter's bowl (a), which some call healing, and the other analysis objects.

Table 1. Numerical list of fractal dimension D.

			(a) 	(b) 	(c) 	(d) 
Micro area	×250	I	2.69	2.65	2.62	2.68
		II	2.48	2.75	2.65	2.66
		III	2.54	2.64	2.55	2.24
	×500	I	2.61	2.62	2.34	2.34
		II	2.22	2.65	2.49	2.12
		III	2.47	2.61	2.47	2.10
Macro area [21]			2.33	2.18	2.19	2.66

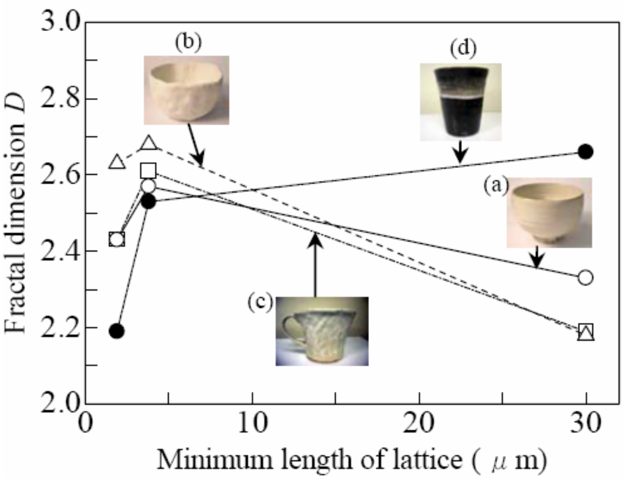

Fig. 4. The relationships between minimum length of lattice and fractal dimension D.

Variation was observed in ln ε-ln *S* relationship shown in Fig. 3, regardless of the analysis object, position of observation, and magnification. Table 2 summarizes fractions of regions where the Richardson effect holds over the whole. It shows a trend by which the region where the Richardson effect holds narrows slightly for smaller fractal dimensions, as is apparent for the ×500 of the black teacup (d). On the other hand, regional fractions scatter for the microscopic regions of the famous potter's bowl (a), the original handmade bowl (b), and the original handmade coffee cup (c), even if they have about the same fractal dimensions. This engenders the conclusion that the region in which the Richardson effect holds is unrelated to parameters that represent healing quantitatively

Table 2. Area of Richardson effect. (%).

			(a) 	(b) 	(c) 	(d) 
Micro area	×250	①	64.3	83.4	65.8	70.9
		②	66.3	84.9	77.4	73.9
		③	74.9	78.9	60.8	71.9
	×500	①	64.3	78.9	64.8	56.3
		②	67.8	78.4	60.8	65.8
		③	59.3	75.9	70.9	47.2

The above discussion reveals that relative self-similarity is verified for fractal properties of healing solid surface properties in microscopic regions representing tactile healing and macroscopic regions representing visual healing. This fractal dimension, averaging microscopic region and macroscopic region, is about D=2.40. Using this value as an index for machining or design will realize a product with surface properties that differ from those of the famous potter's bowl (a), but which have the same healing effect.

6. Conclusions

In this study, quantitative evaluation of surface properties was conducted using fractal dimensions for microscopic regions of various bowls as the second stage of establishment of technology to transfer healing and fluctuation to die-forged surfaces.

Specifically, fractal analysis methods that extended Mesh method to a 3-D problem were applied to surface properties analysis of various potteries; the extensive applicability of analytical methods was verified. Moreover, it was demonstrated that fractal dimension *D* is useful as an index for machining or design in transfer of healing, together with fractal analysis results for macroscopic regions in the first report. The following results were obtained from such a series of studies:

(1) The Richardson effect was observed in surface properties of four pottery objects: the famous potter's bowl (a), the original handmade bowl (b), the original handmade coffee cup (c), and the black teacup (d). The fractal properties on the surfaces of pottery were verified.

(2) Investigation of fractal dimension *D* and self-similarity revealed that healing surface properties of the famous potter's bowl (a) have distinctive properties compared to the other analysis objects.

(3) Results revealed that relative self-similarity is verified for fractal properties of healing solid surface properties in the microscopic region representing tactile healing and in the macroscopic region representing visual healing.

(4) Scattering in regions where the Richardson effect

holds is considered to be quantitatively unrelated to parameters that represent healing.

(5) Comprehensive fractal analysis, integrated for the macroscopic region and microscopic region, suggests that fractal dimensions represent healing as about D=2.40. This value is useful as an index for machining or design for transfer of healing qualities.

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