

Quantitative analysis on macro-fluctuation of several bowls by laser microscope and FFT

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In order to evaluate the fluctuation and the surface irregularity of the famous potter's bowl and other analytical objects, an analytical procedure was developed by applying the concept of fractals, a hyperbola model of the Richardson effect, and FFT analysis. The main results of this study are summarized as follows: (1) To evaluate the irregular surface of fluctuations quantitatively, an analytical system using a high-resolution laser sensor was developed, and an analytical-procedure-developed Mesh method was established. (2) It was found that the famous potter's bowl has a fractal nature and a relative self-similarity in wide resolution ranges. (3) The geometrical irregularity of the surface can be well evaluated by combining the fractal dimension D and the FFT parameters. (4) In order to apply the design of a mechanical structure in a later study, the target value of the fractal dimension was estimated as $D=2.33$.

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1. Introduction

In recent years, the expression "healing", represented by $1/f$ fluctuations is frequently used. Most typically classical music, along with light, patterns, heat, wind, and shape comfort humans. This is because biological rhythms of physiological actions such as cardiac beats and alpha brain waves have $1/f$ wavelengths like these fluctuations.

On the other hand, in the scene of metalworking, productivity and efficiency are of greatest importance. As a result, products with "warmth" and "taste" by skilled craftsman's handwork are being crowded out, along with technical problems. There are some trials of expert systems, which incorporate masters' works by skilled craftsmen into control programs for machinery. However, they have not been put into practical use yet, and additional studies from other aspects are needed.

Against such a background, this study particularly addresses healing and fluctuation according to the surface properties of a solid. Our ultimate goal is to establish technology that transfers this fluctuation on die forging surfaces or machinery structure surfaces. Die forgings are manufactured in a mass-production line. Therefore, only efficiency has been considered as important in their design and production. Products manufactured using this transfer technology will have extra value of a peculiar healing effect. Such products will provide healing effects to workers also during manufacturing processes, as well as to consumers.

This report addresses macroscopic surface properties of pottery by a famous potter, a masterpiece of fluctuation

and healing, and discusses its quantitative evaluation including fractal dimension D using fractal geometry conducted as the first stage. Specifically, we have aimed at obtaining quantitative data of effective healing components towards future transfer technology establishment by means of quantitative evaluation using fractal dimension D for surface properties. It is no imitation or pastiche of fluctuation and healing of pottery by a famous potter: this healing component is evaluated quantitatively using fractal dimensions, and transfer technology is established based on these quantitative data. This is the most important characteristic of the contribution made by this study.

2. Analysis object and experimental procedure

The present analysis targeted macroscopic solid surface properties of a bowl by a famous potter, as shown in Fig. 1 (a), which some call healing and chic. As objects for comparison, vessels of various surface properties were used, as in the original handmade bowl in Fig. 1 (b), (c) an original handmade coffee cup, and (d) a black teacup. The original handmade bowl (b) copies the famous potter's bowl (a) in its handiwork, and the comparison of both is expected to reveal differences in talent between a famous potter and an amateur. The original handmade coffee cup (c) and the famous potter's bowl (a), although they have different shapes, possess innate warmth from being produced by the artist's handiwork. Because the black teacup (d) is a cheap

commercial product of automated machining, a result is expected to support quantitatively a very ambiguous expression that the famous potter's bowl (a) has healing power because of its inherent value compared with that of (d).



(a)



(b)



(c)



(d)

Fig. 1. Photographs of analysis object: (a) Famous potter's bowl; (b) Original handmade bowl; (c) Original handmade coffee cup; (d) Black teacup.

This study defines "macroscopic" as follows: healing effects are evaluated by visual observation of a 30mm×30mm square area. Although each vessel is colored by its maker, this study ignores the color so that healing is assessed only by surface properties.

The measurement instrument employs a noncontact laser displacement gauge (Type LJ; Keyence Co.), whose overview is shown in Fig. 2. An analysis object is put on the turntable with a rotating speed of 1.40rpm, and red semiconductor laser light with 30mm width is irradiated on it. The data sampling cycle of the data logger is 0.03s. Therefore, the unevenness data of the 30mm×30mm square area can be collected by rotating the object for 6s. The physical 30mm×30mm square area is mapped onto a 200dot×200dot region on the LCD screen for computer processing of this image. That is, one interval of sampling data corresponds directly to 1pixel (1dot×1dot) of a LCD screen. Accordingly, 1pixel on the LCD corresponds to a 0.15mm×0.15mm physical area, i.e., a square area of the size on the pottery object.

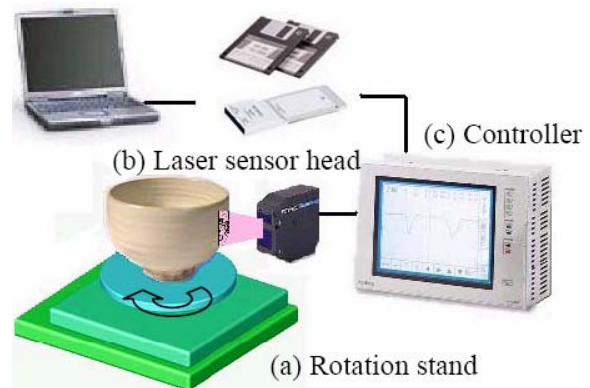


Fig. 2 Schematic illustration of laser sensor system.

3. FFT analysis procedure and result

Maekawa et al. [1] proposed application of frequency power spectrum analysis as an objective index of decision-making about design, and assessed affective factors such as fluctuation from the correlation of frequencies obtained by power spectrum analysis. Moreover, they reported that FFT analysis of density and frequency indicates that pottery objects have $1/f$ fluctuation. Therefore, if the present analysis pottery objects have sufficient fluctuation and healing, an inversely proportional relationship of $1/f$ should pertain between both. This report mainly addresses the fractal quantitative evaluation of the overall surface properties for convenience in future transfer technology establishment. The below mentioned fractal analysis targets the surface components of analysis objects. Therefore, quantitative data of fluctuation and healing obtained using fractals will simplify its transfer. However, because the FFT analysis mentioned here targets line components, the addition of dimensionality is necessary. Hence it is considered difficult to transfer these quantitative data onto a surface.

Therefore, to investigate correlation between FFT analysis results and fractal analysis results for reference, power spectrum analysis by FFT was conducted along one of the longitudinal or transverse directions of digital data.

An arbitrary 128dots continuous in the longitudinal or transverse direction were extracted from the unevenness data of a 200dot×200dot square obtained using the measurement method described in the preceding chapter. Then they were digitally input to the FFT analyzer (Model CF6400; Ono Sokki Co., Ltd.), and the relationship between frequency and the power spectrum was investigated. This relationship is expressed as $1/f^x$, where the value of x is shown in Table 1. Consequently, a $1/f$ fluctuation becomes apparent as x approaches 1.00.

Table 1. Numerical list of FFT analytical results.

Analytical object	Vertical	Horizontal
(a) Famous potter's bowl	0.93	0.88
(b) Original handmade bowl	0.83	0.90
(c) Original handmade coffee cup	0.88	0.87
(d) Black tea cup	0.82	0.81

In the case of chaotic fluctuation, no correlation between frequency and power spectrum is apparent, and a spectrum stays constant at $1/f^0$ to form a horizontal straight line. This is called $1/f^0$ fluctuation, which is typically emitted by strong stimulative sound or unpleasant colors. On the other hand, regular sounds such as the ticking of a second pointer of a clock or mechanical electronic sound indicates strong correlation between both, and it is expressed as $1/f^2$. In contrast to both, $1/f^1$, i.e., $1/f$ fluctuation, is located in between, which is in the state where irregularity and regularity harmonize. The present result reveals that x of the famous potter's bowl (a) is closest to 1.00 among the vessels in the average of longitudinal and transverse directions. Therefore, this result is assumed to represent relative $1/f$ fluctuation.

4. Fractal analysis procedure of fluctuation surface properties

The authors [2-5] have reported several works based on fractal analytical methods in the field of machining and fracture mechanics. Higuchi et al. [6] proposes a design method of concavo-convex geometry on the surface of a grinding stone using this procedure. Thus the analytical method mentioned in this chapter is also considered to have sufficient applicability for the establishment of fluctuation transfer technology.

The fractal analysis method proposed by the present authors extends Mesh method [7] in a plane problem to 3-D. Because this method is proven to enable quantitative assessment of irregular properties of various surfaces of metallic materials, it is also expected to be fundamentally applicable to analysis objects with fluctuation in this report.

The Richardson effect [8], verified for the

complicated closed curve on a plane like a coastline with complicated concavo-convexity by L. F. Richardson, can be extended to 3-D morphology. Then the following inference holds: an object solid is assumed to be subdivided into some densely packed cubes, for which the edge length is ϵ and the number of cubes which intersect the surface of the solid is n . If this solid has fractal properties, the relationship of Eq. (1) holds between n and ϵ :

$$n = F\epsilon^{-D} \quad (1)$$

where F is a constant and D expresses fractal dimension. Because the area of a square of edge length ϵ is given by ϵ^2 , the surface area S of this solid is assumed to be expressed by Eq. (2) on the basis of n , as

$$S = n\epsilon^2 = F\epsilon^{2-D} \quad (2)$$

The logarithm of both sides yields

$$\ln S = \ln F + (2-D) \ln \epsilon \quad (3)$$

Therefore, if fractal properties exist in an irregular solid shape, a linear relationship should hold between edge length of the divided cube ϵ and surface area S in double logarithmic coordinates.

To analyze the Richardson effect using Eq. (3), the surface area S of an irregular solid must be computed with measuring unit length ϵ varied. Fig. 3 shows that the fluctuation surface properties of Fig. 3 (a) are converted into the fluctuation data of height at the tetragonal lattice points of edge length ϵ in Fig. 3 (c). Then surface area S is computed as the sum of areas of triangular surface elements connected based on Heron's formula. A computer program was coded using Visual Basic 6.0 (Microsoft Corp.) for this series of analytical procedures in this study. Analyses were carried out continuously.

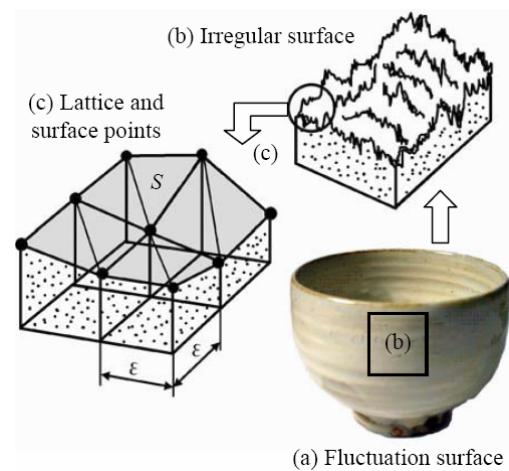


Fig. 3. Replacement of irregular surface by multifacet surface.

The fractal dimension D of surface properties is obtainable as follows: various values are set to ϵ with this procedure; surface area S is computed for each ϵ ; the result

is plotted on the $\ln \varepsilon$ - $\ln S$ space; and finally D is computed from the gradient of the regression line of Eq. (3). Because this regression line is necessarily downward-sloping, the fractal dimension D of fluctuation surface properties is always D larger than 2.0. This fact implies that because a plane is 2- D , a solid has a real dimension more than 2 in terms of fractals, no matter how flat and smooth it might be.

5. Analysis results and discussion

5.1 Fractal dimension and oblique hyperbola

The result of fractal analysis of the surface properties of various potteries indicates that fractal properties showing the above-mentioned Richardson effect rather rarely stands, where $\ln \varepsilon$ - $\ln S$ linearity is assured over the analysis range. The analysis result in this study presents that S deviates from linearity to form a curve as a certain limit of ε is exceeded. Therefore, the $\ln \varepsilon$ - $\ln S$ relationship is displayed using an oblique hyperbola [9] given by the following equation, as in the authors' fractal analysis of a machined surface [2]. This oblique hyperbola is often used for S - n relationship analysis of fatigue testing result,

$$(\ln S - E)(\ln S + A \ln \varepsilon - B) = C \quad (4)$$

Each parameter of Eq. (4) has meanings shown in Fig. 4. In this procedure, the overall measurement result is first approximated by an oblique hyperbola. Then the inclined directrix is regarded as the straight line of Richardson effect. That is, fractal dimension D will be obtained from the gradient of this oblique hyperbola $A=2-D$. The inclined directrix is determined by linear approximation of the upper half of the measured result, where the measurement points can be visually regarded to form a straight line, using the least-squares method.

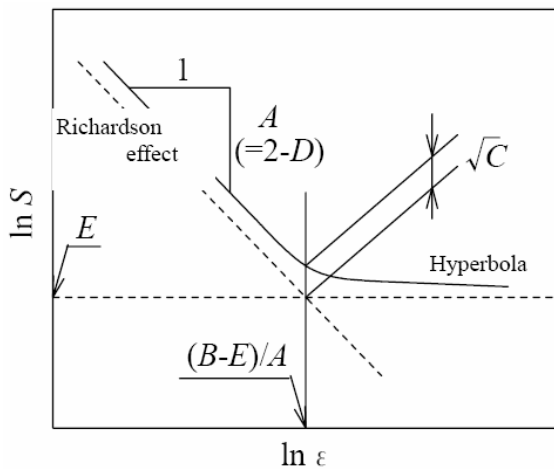


Fig. 4. Schematic illustration of hyperbola model and $\ln \varepsilon$ - $\ln S$ relationship [9].

Sakai et al. [10] computed fractal dimensions in the nonlinear $\ln \varepsilon$ - $\ln S$ relationship measurement in fractal analysis, dividing the range into several regions according to ε . However in this study, the identical tendency is observed in the plots of all analysis objects at $\ln \varepsilon$ nearly equals 0 or greater. For that reason, fractal dimension was computed only from the inclined directrix, without performing this procedure.

5.2 Fractal analysis result of fluctuation surface properties

The $\ln \varepsilon$ - $\ln S$ relationships were obtained for the surface properties of the various pottery objects shown in Chapter 2 with the above-mentioned analysis procedure, as illustrated in Fig. 5. In subdividing the analysis area using the laser displacement gauge of 200dot×200dot, ε was set as 1, 2, 4 ... pixels. These values correspond to equally dividing one edge exactly into 200, 100, 50 ... divisions, respectively. Thus, the surface area S of the virtual solid was analyzed with edge length ε one by one as 0.15, 0.3, 0.6 ... mm, and plotted on the figure.

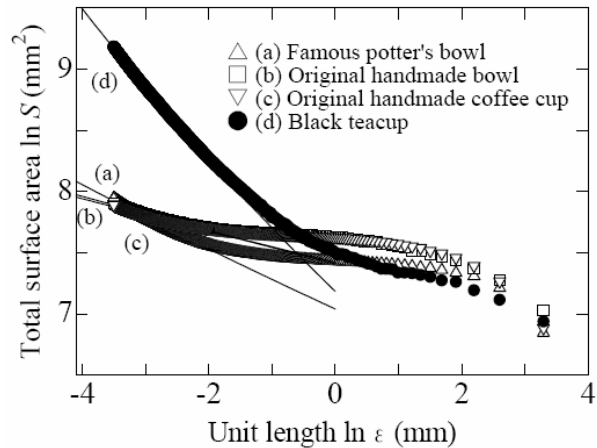


Fig. 5. $\ln \varepsilon$ - $\ln S$ relationships for all analytical objects.

Fractal analysis shown in Fig. 5 was conducted continuously in three analysis areas for each analysis object. Table 2 summarizes the averages of fractal dimensions from the gradient of the inclined directrix. The fractal dimensions D of the original handmade bowl (b) and coffee cup (c) are smaller, compared with $D=2.33$, for the famous potter's bowl (a), whereas that of the black teacup (d) is much greater. A comparison of the famous potter's bowl (a) and the black teacup (d) reveals marked differences in the fractal dimension because of the difference in price and production processes. Therefore, it is suggested that an ambiguous expression that an expensive masterpiece has healing power because of its price value is verified quantitatively using fractal dimensions. The famous potter's bowl (a), the original handmade bowl (b) and coffee cup (c) are all made by hand; their $\ln \varepsilon$ - $\ln S$ relationships show the same tendency overall. However, fractal dimensions allow us quantitative evaluation of talent differences between a famous potter

and an amateur, i.e. a healing component.

Table 2. Numerical list of fractal dimension D .

Analytical object	Fractal dimension D
(a) Famous potter's bowl	2.33
(b) Original handmade bowl	2.18
(c) Original handmade coffee cup	2.19
(d) Black teacup	2.66

Relative $1/f$ fluctuation was verified in the analytical results of the famous potter's bowl (a) with the above-mentioned FFT. The fractal dimension of this fluctuation is estimated as about 2.33; this value seems to represent a healing effect.

6. Conclusions

In this study, quantitative evaluation of surface properties was conducted using FFT parameters and fractal dimensions for various pottery objects as the first stage of establishment of technology to transfer healing and fluctuation on die forging surfaces. Specifically, fractal analysis methods which extended Mesh method to a 3-D problem were applied to surface properties analyses of various potteries. The extensive applicability of an analytical method was verified. The following results were obtained from this series of studies:

(1) Power-spectrum analysis for the surface properties of some potteries by FFT demonstrated relative $1/f$ fluctuation in the famous potter's bowl (a).

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

(3) Fractal dimension D has enabled quantitative evaluation of very ambiguous healing component, attributable to differences in price, production processes, and talents of the manufacturers or artisans.

(4) Both FFT analysis and fractal analysis results for the famous potter's bowl (a) suggest that its fractal dimension, representing fluctuation and healing, is about 2.33.

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