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프랙탈 파라미터에 의한 마멸분 형태특징 분석

조연상*, 김영희**, 박흥식#

Analysis of Shape Characteristics of Wear Particles with Fractal Parameters

Yon-Sang Cho*, Young-Hee Kim** and Heung-Sik Park#

ABSTRACT

The fractal dimension aims to quantitatively define the irregular characteristics of the shape in nature. It can be useful in describing morphological characteristics of various wear particles. This paper was undertaken to diagnose failure condition for sliding members in lubrication using fractal dimension. The experiments were undertaken to analyze the shape of wear particles and to diagnose failure condition for sliding members in lubrication using the image processing and the fractal parameters. It was possible to diagnose wear mechanism, friction, and damage state of machines through analysis of shape characteristics for wear particle in driven condition using fractal parameters.

Key Words : Wear Particle, Shape Characteristics, Image Processing, Fractal Dimension

1. Introduction

The morphology of wear particlesis directly related to the damage and failure to moving system from which the particles were generated. Observing wear particles in oil is an effective way to estimate the damage to a machine[1]. In order to analyze the shape characteristics of wear particles, the image processing and the fractal dimension were suggested by many researchers[2-6]. The fractal dimension[2, 7] aims to quantitatively define the irregular characteristics of the shape in nature. It can be useful in describing morphological characteristics of various wear particles. The digital image processing is used to calculate the shape parameters such as area, diameter, and roundness and the fractal parameters of wear particles. But fractal parameters have not yet been constructed on the morphological characteristics of wear particles, because of insufficient knowledge about a concept of the fractal dimension.

In this study, the experiments were undertaken to analyze the shape of wear particles and to diagnose failure condition for sliding members in lubrication using the image processing and the fractal parameters. The wear test was performed under different experimental conditions using the ball on disk type

* Dept. of Mechanical Eng., DongA University
** Materials Science Eng., DongA University
# C. A. : Dept. of Mechanical Eng., DongA University
E-mail : parkhs@dau.ac.kr

wear test device, and three kinds of materials (S45C, STS304 and LBC3) were rubbed in paraffin series base oil. The generated wear particles were extracted using the 0.45㎛membrane filter. The computer image processing was used to get the fractal parameters for shape analysis of wear particles. These parameters were defined as texture fractal dimension (Dt), structure fractal dimension (Ds), and total fractal dimension (D) and the shape characteristics of wear particles were represented as numerical values. With these, the shape characteristics and types of wear particles are researched.

2. Experiment

2.1 Friction and wear test

The Ball-On-Disk type tester as shown in Fig.1 was used for friction and wear experiment. The ball specimen of alumina ceramics was 5mm in diameter. The disk specimens of SM45C, STS304 and LBC3 used for parts of automobiles or machines were 50 mm in diameter. The lubricant oil was pure paraffin base oil(8.2cSt @40℃). Oil was supplied on a point of contact between specimens through a silicon tube. The oil bath was set under the contact point. The applied load was set up at 3kg and the sliding speed was 2.83m/min. The sliding distance was from 0m to 510m and oil was exchanged per 170m. Oil in the bath was mixed up with normal hexane of the same amount, and the wear particles generated in each experimental condition were extracted using 0.45㎛membrane filter.

2.2 Image processing

The algorithm of the digital image processing, as shown in Fig. 2 aimedto calculate fractal parameters of extracted wear particles. Images of these particles were captured by a digital camera on the optical microscope with transmitted halogen lights, and had the resolution of 2272×1704 pixels that were 24bit (RGB 8-8-8) per pixel. The transmitted images were transformed into the threshold images with a threshold value selected from the histogram in order to clearly extract the boundary and morphologyof wear particles. With these transmitted images, the fractal parameters and shape characteristics of wear particles such as area, diameter, and roundness were calculated. The digital image processing software made by ourselves with the Visual C++ language.

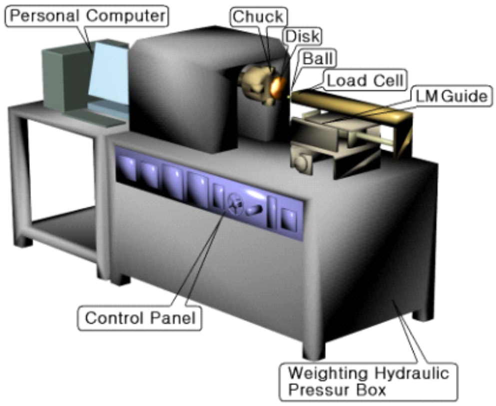


Fig. 1 Schematic diagram of pin on disk type wear tester

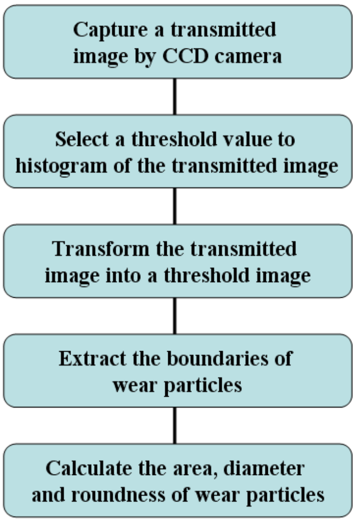


Fig. 2 Image processing algorithm

It is needed that the boundary of a particle is searched to calculate the fractal dimension and the fundamental shape information. The boundary searching method as an important algorithm for the shape analysis codes the shape of a particle with tracking boundary pixel according to the order.

(a) Before process (b) After process

Fig. 3. Result of searching process for the boundary

Fig. 3 shows the result image of searching boundary of a wear particle generated by the applied load of 3kg. In this figure, it is shown that particle's periphery is extracted certainly. With the information of periphery, the fractal parameters were calculated for the shape of a wear particle.

2.3 Fractal parameters

In order to analyze irregular shape characteristics such as a coastline, the fractal dimension was suggested by Mandelbrot and R.F.Voss[7]. In this study, the shape characteristics of wear particles were analyzed with this dimension.

Fig. 4 shows the method to calculate the fractal parameters from the boundary data of wear particles in Fig. 3 which were extracted through image processing. The length of pixel step and the perimeter at step length for the boundary pixels of wear particle were changed to logarithm values and the linear relation between two parameters was determined by the method of least squares. Fractal dimensions are calculated by the line gradient(1-D). In this, the D means fractal dimension. As the shape of wear particles is more rough and irregular, the fractal dimension is higher. In the graph, two fractal characteristics are represented, as shown in Fig. 4. Generally, under 100 pixels, fractal dimensions describe the texture characteristics of particle boundaries such as roughness and smoothness degrees in small area, and over 100 pixels, describe the structure characteristics such as aspect and roundness. In this study, boundary fractal parameters were defined as texture fractal dimensions (Dt) under 100 pixels, structure fractal dimensions (Ds) over 100 pixels, and total fractal dimensions (D) for all pixels. As mentioned above, the morphological characteristics of wear particles were represented in numerical values.

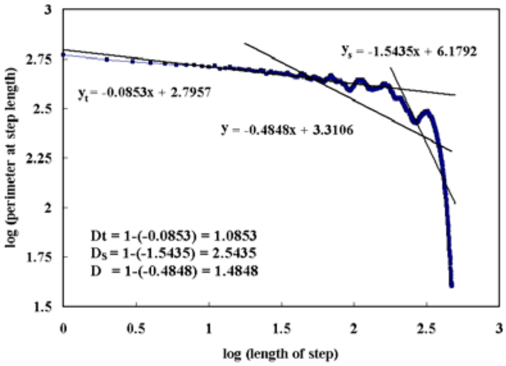


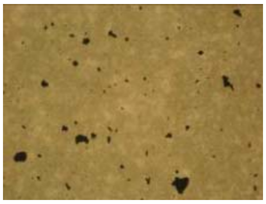
Fig. 4 Fractal parameter of boundary of wear particle from Fig. 3

3. Results and discussion

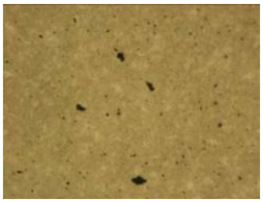
3.1 Shape characteristics of wear particles

Fig. 5 shows the transmitted images of wear particles of each material when the sliding distance is 340m. In (a)LBC3, the relatively large chunk or fatigue particles are generated most, but in (b)SM45C, the relatively small rubbing wear particles or spherical particles and a few fatigue particles are generated by abrasive wear. (c)STS304 generates many chunk or fatigue particles and cutting wear particles by hard abrasive wear.

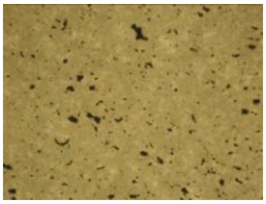
Typical shape parameters of wear particle are 50% volume diameter and roundness calculated by digital image processing, The 50% volume diameter is a diameter as sum of volume of wear particle, which are sorted according to an ascending order, and is 50% of total volume. It is a size of a typical particle in an experimental condition. And roundness is the ratio of a periphery of a circle which is equal to the area of particle and a real periphery. As it is near to 1, the shape of particle is more similar to a circle.



(a) LBC3



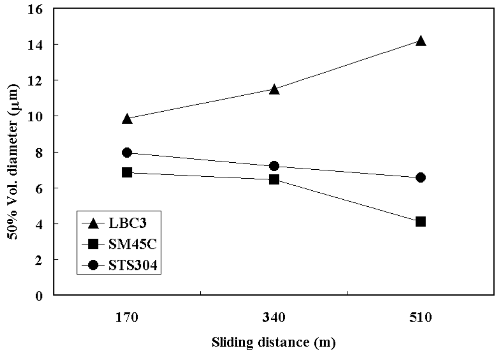
(b) SM45C



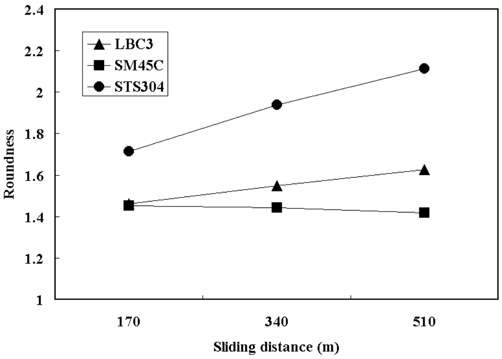
(c) STS304

Fig. 5 Transmitted images of wear particles, sliding distance : 340 m

Fig. 6 shows the variations of typical shape parameters of wear particles occurred from each material according to the sliding distance. In (a) 50% volume diameter, the size of LBC3's particle are comparatively larger than the others, and becomes larger as sliding distance increases, and SM45C's and ST304 are smaller to that. In (b) roundness, the SM45C is similar over all as sliding distance increases, STS304 is more irregular than the other materials. These results show that wear particles shown in Fig. 6 can be clearly defined as quantity value on the shape characteristics. However, roundness calculated by image processing can not confide when the size of particle is small, because of the error by the influence of digital resolution. In this study, a shape irregularity of wear particle was analyzed with fractal parameters which were strong to the error.



(a) 50% Vol. diameter



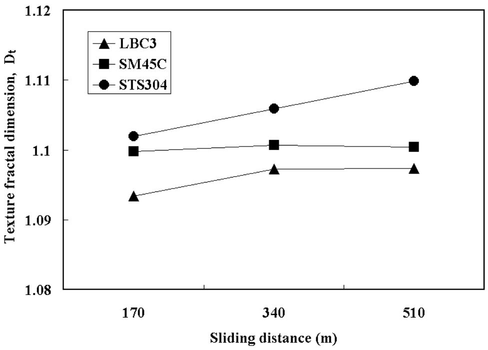
(b) Roundness

Fig. 6 Shape parameters of wear particles on materials

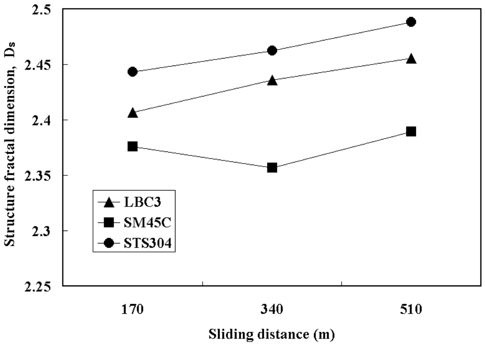
3.2 Fractal parameters of wear particles

Fig. 7 shows the variation of average of (a)texture fractal and (b)structure fractal dimensions of wear particles as sliding distance increases. In (a)texture fractal dimension which represents a delicate variation of boundary such as a roughness, STS304's shape characteristics of particles are roughness, but LBC3 is mild mostly. In (b) structure fractal dimension which describes a delicate variation of boundary such as roundness or aspect, the STS304's variation of boundary is larger than the others like (b)roundness in Fig. 6.

The variation of average of total fractal dimensions, as shown in Fig. 8, describes general morphological characteristics of wear particles. In this figure, according to the increase of the sliding distance, wear particles are mostly complicated and irregular.And we could know that the shape characteristics of wear particles of ST304 are more irregular and rougher than the others.



(a) texture fractal



(b) structure fractal

Fig. 7 Average of fractal parameters of wear particles

Therefore, the fractal parameters sufficiently describe the shape characteristics of wear particles shown in microscope images. The size and fractal parameters of wear particle are useful in diagnosing the wear mechanism, friction, and damage state of machines.

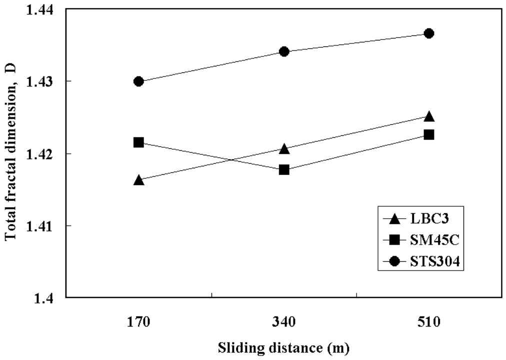


Fig. 8 Average of total fractal dimension of wear particles

4. Conclusion

We have the following conclusions by using the image processing and the fractal parameters to analyze wear particles through the friction and wear test depending on working conditions.

1. In LBC3, the relatively large fatigue particles are generated mostly, but in SM45C, small rubbing wear particles or spherical particles and a few fatigue particles are generated by abrasive wear. STS304 generates many fatigue particles and cutting wear particles by hard abrasive wear.
2. In the result of analyzing the shape of wear particles with fractal parameter, the particles are more complicated and irregular depending on theincrease of sliding distance, and the shape characteristics of wear particles of ST304 are more irregular and rougher than the others.
3. The fractal parameters sufficiently describe shape characteristics of wear particles, and they are useful for diagnosing wear mechanism, friction, and damage state of machines.

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