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Theoretical Derivation of Mean Cutting-Point Space of Grinding Wheel

Jumpei Kusuyama [a, 1], Michinosuke Tanaka, Bima Kawase and Yohichi Nakao
[a] *Kanagawa University, 3-27-1 Rokkakubashi, Yokohama, Kanagawa, Japan*

Abstract. In a surface grinding process, a successive cutting-point space of grinding wheel affects the maximum abrasive grain depth of cut, which is a major factor affecting grinding characteristics such as the grinding forces and temperature. These characteristics degrade the productivity and machining accuracy. Therefore, we have to clearly define the successive cutting-point space. There are, however, few reports on the derivation method of the theoretical formula since abrasive grains inside the wheel are randomly distributed. This study aimed to theoretically derive the mean cutting-point space and to clarify the successive cutting-point space. We proposed a new derivation method for the mean cutting-point space, which was measured by mapping the diamond wheel surface using an EPMA. The theoretically derived mean cutting-point space was then compared with the measurement results.

Keywords. Abrasive grain, Grinding, Mean cutting-point space, Successive cutting-point space.

1. Introduction

Many products are manufactured using a grinding removal process. In the surface grinding process, a successive cutting-point space which is the space of the cutting edges in line with the grinding wheel rotation direction, affects the maximum abrasive grain depth of cut (Fig. 1). It is expressed by a successive cutting-point space, grinding wheel peripheral speed, work piece feed rate, grinding wheel diameter, and depth of cut. The maximum abrasive grain depth of cut is a major factor affecting the grinding characteristics such as the grinding forces and temperature. These characteristics degrade productivity and machining accuracy of grinding processes.

Accordingly, we have to clearly define the successive cutting-point space. There are abundant reports on the successive cutting-point space, whereas there are few reports on the derivation method using the theoretical formula [1][2][3][4]. This is because abrasive grains inside the grinding wheel are randomly distributed.

This study aims to theoretically derive the mean cutting-point space and to the successive cutting-point space. We proposed a new derivation method for the mean cutting-point space, which utilizes only the grain size and concentration of the grinding wheel. The concentration is in general considered to be four times the volume percentage of the abrasive grains. Furthermore, the abrasive shape was assumed to be a regular icosahedron. In our proposed method, the mean cutting-point space can be measured by mapping the diamond grinding wheel surface using an electron probe micro analyzer. The number of abrasive grains was counted in the binarized observation results, and

[1] Corresponding Author. ft102043hl@kanagawa-u.ac.jp

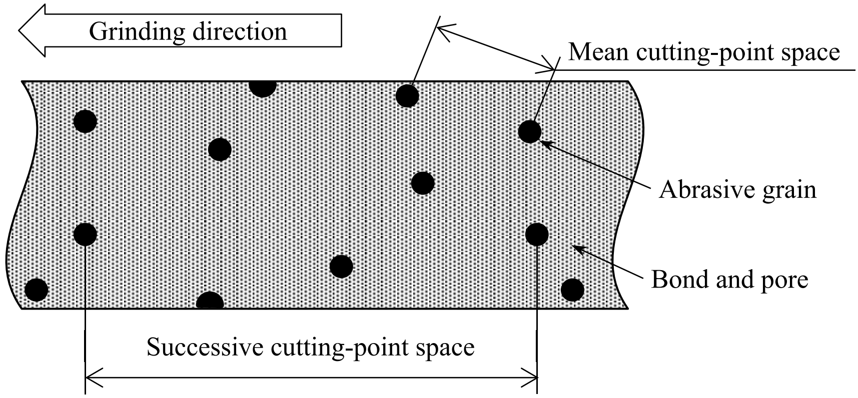


Fig. 1 Grinding surface of grinding wheel

redistributed in an equilateral triangular lattice within the observation area. The length of the side of this equilateral triangle is defined as the mean cutting-point space. The theoretically derived mean cutting-point space is then compared with the measurement results. The findings showed that the measured value is consistent with the results derived by the proposed method.

2. Theoretical derivation of mean cutting-point space

First, the abrasive shape is now assumed to be a regular icosahedron. In this study, the basic derivation of the volume and the normal projection area of icosahedron is omitted because it is different from our main purpose. Furthermore, the length of a side of the regular icosahedron is simply assumed to be *l*. Based on the assumed simplified model of a grinding wheel, the abrasive grain can be in a hexagonal prism with a bond and pore as shown in Fig. 2 (a). This hexagonal prism is assumed to densely form a grinding wheel as shown in Fig. 2 (b).

Second, we theoretically determine the projected area and volume of the modelled regular icosahedron. Assuming that the diameter of a circumscribed circle on the considered icosahedron and that of the abrasive grain is equal, the length *l* of the side is given by

$$l = \frac{\sqrt{50-10\sqrt{5}}}{10} d_0 \tag{1}$$

where d_0 is the average diameter of the abrasive grain that is modelled circumscribed circle.

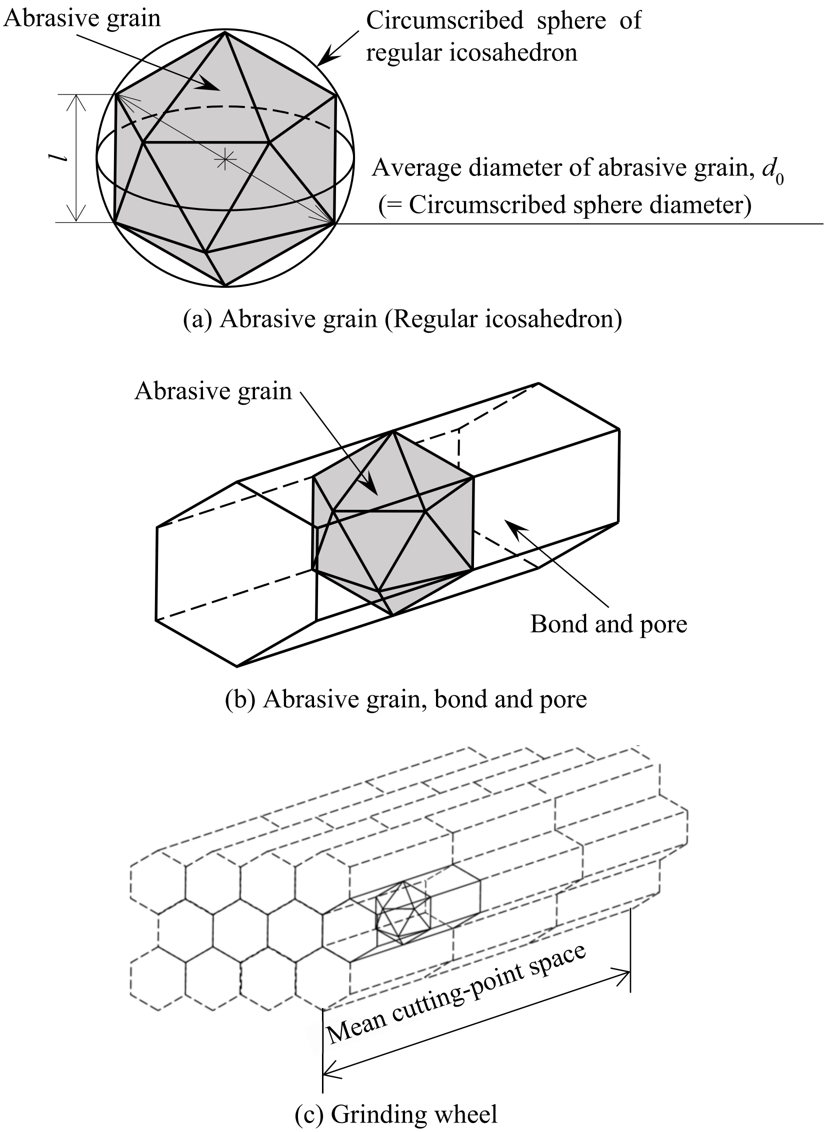
From Eq. (1), the projected area of the icosahedron, *S*, is given by

$$S = \frac{3\sqrt{3}}{8} d_0^2. \tag{2}$$

Furthermore, the volume of the icosahedron is given by

$$V = \frac{100\sqrt{10+2\sqrt{5}}}{3C} d_0^{\,3} \tag{3}$$

where C is the concentration of the grain of the grinding wheel.



(a) Abrasive grain (Regular icosahedron)

(b) Abrasive grain, bond and pore

(c) Grinding wheel

Fig. 2 Model of grinding wheel

Generally, it is considered that an abrasive grain is released when the projection height of abrasive grain becomes one-third or more of abrasive grain diameter. This is called ‘self-dressing’. From Eqs. (2), (3), and the self-dressing assumption, the theoretical formula of the longitudinal direction length of the hexagonal prism, namely, mean cutting-point space, ω, is given by

$$\omega = \frac{800\sqrt{30+6\sqrt{5}}}{9C} d_0. \tag{4}$$

3. Measuring of mean cutting-point space using EPMA

In this study, a diamond grinding wheel surface was observed, and X-ray mapping was conducted by an Electron Probe Micro Analyzer (EPMA) to derive the measure mean cutting-point space ω. Using image processing technique, the observed image was then binarized and the number of abrasive grains was counted. Based on the measured number of abrasive grains, the mean cutting-point space ω was then calculated by assuming that the abrasive grains were distributed as shown in Fig. 3.

Figures 4 (a) and (b) show the microscopic observation and the EPMA observation result of the grinding wheel surface after it was binarized, respectively. The diamond grinding wheel used in this study was utilized for the machining of Si wafer. The average grain diameter, d_0, and concentration, C, of this grinding wheel are 0.98 μm and 95 (volume ratio 23.75 %) respectively.

In Fig. 4 (b), the number of abrasive grains is 2959. The mean cutting-point space using EPMA obtained under the assumption shown in Fig. 3 is 5.830 μm. Furthermore, substituting the specifications of the grinding wheel into Eq. (4), the mean cutting-point space becomes 6.042 μm. The discrepancy between the two results was about 3%. There are two reasons for this: the ambiguous part in the observed image could not be precisely binarized. In addition, the abrasive grains inside the grinding wheel could not be measured correctly.

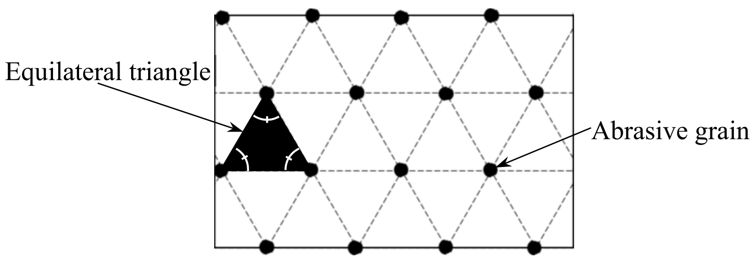
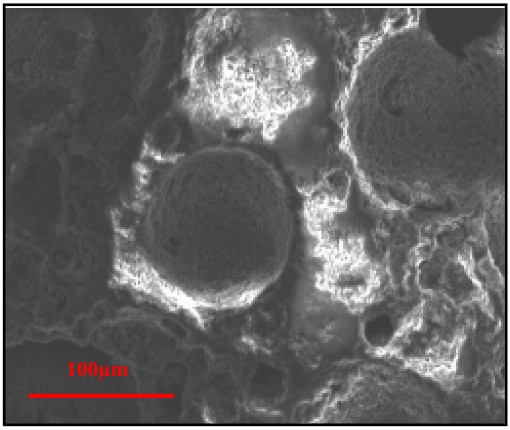
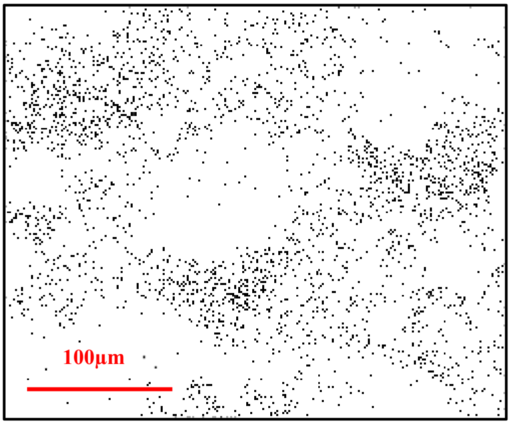


Fig. 3 Distribution of abrasive grain



(a) Microscope image



(b) EPMA

Fig. 4 Observation results of wheel surface image

We compared a conventional theoretical formula and the theoretical derivation formula proposed in this study [5]. The mean cutting-point space, ω', deduced by the conventional theoretical formula, is given by

$$\omega' = \sqrt{\frac{\pi}{6V_g}} \times d_0 \tag{5}$$

Here, the average abrasive grain diameter is d_0, and the abrasive grain volume percentage is Vg. By substituting the grinding wheel specifications into Eq. (5), ω' is obtained to be 1.455 μm, which is significantly different from the EPMA result. Therefore, it turns out that the proposed theoretical derivation formula is more effective to predict precisely the mean cutting-point space than the conventional theoretical formula.

4. Conclusion

We proposed a new theoretical formula for mean cutting-point space in order to derive successive cutting-point spacing. The abrasive grain distribution was measured by an EPMA to verify the validity of the theoretical formula. The proposed theoretical formula of the mean cutting-point space corresponded to the observation result of the EPMA. From our results, the proposed theoretical formula is more useful than the conventional theoretical formula.

In future, it is necessary to evaluate whether the proposed theoretical formula can be applied to other grinding wheels, namely different abrasive grain types, sizes, and concentrations.

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References

[1] S. Matsui, Some Considerations on Successive Cutting Edge Spacing on Wheel Surface in Grinding Process, Japan Society for Precision Engineering, 43, 4 (1977), pp. 476-482 (in Japanese).
[2] K. Li, W. Liao, Modelling of ceramic grinding processes Part I. Number of cutting points and grinding forces per grit, Journal of Materials Processing Technology, 65, 1 (1997).
[3] T. Nakajima, M. Yoshikawa, S. Tsukamoto and K. Takehara, Simulation of Ground Surface Profile Generation with Measured Distribution of Mounting Spring Constant, Dimensional Position and Shape of Abrasive Grains, Japan Society for Precision Engineering, 64, 7 (1998), pp. 1072-1077 (in Japanese).
[4] N. Takenaka and S. Sasaya, On Grinding Action of Grinding Wheels: 2nd Report, Number of Grains per Unit Area and Mean Distance between Grains on Working Surface of Grinding Wheels, Transactions of the Japan Society of Mechanical Engineers, 26, 163 (1960), pp. 403-407 (in Japanese).
[5] S. Okuyama, A. Une, A. Yui and H. Suzuki, Fundamentals of Machining Technology, CORONA PUBLISHING CO., LTD., (2013) (in Japanese).