In-situ 3-D Observation of Active Grain Distribution on a Grinding Wheel and Introduction of Experimentally Evaluated Parameters to Grain Depth of Cut

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1. Introduction

Protrusion height distribution of active grains on a grinding wheel is one of the predominant parameters on grinding performance including surface roughness and surface integrity, because it dominates grain depth of cut. Especially for grinding of brittle materials, material removal mode in machining or ductile/brittle mode is decided by grain depth of cut. However there are few reports on protrusion height distribution of active grains, although there are many reports on only grain distribution not including the information on protrusion height. It is caused by two reasons. One is that the importance of protrusion height distribution had not been fully recognized until ductile mode grinding technology of brittle materials became a great target to be developed. Another is that the right measuring method of the distribution or an in-situ 3-D observation method of active grain distribution on a grinding machine has not existed. This paper describes the method of in-situ 3-D observation of active grain distribution and introduction of parameters derived from the observation to grain depth of cut.

2. Protrusion height distribution and grain depth of cut

Grain depth of cut was formulated geometrically by Malkin and others. The formula is as follows

$$d_g = 2a\frac{v_w}{v_s}\sqrt{\frac{d}{D_e}} \qquad (1)$$

d_g : grain depth of cut,
v_w : work-piece velocity, v_s : wheel velocity
___ D_e : equivalent wheel diameter d : wheel depth of cut
a : spacing between abrasive grains

This formula expresses the grain depth of cut done by the abrasive grain proceeded by a grain with the same protrusion height. This means that the formula is based on the imaginary grinding wheel with consecutive abrasive grains to be spaced in constant distance and same in protrusion height, and without both waviness on a wheel surface and run-out. However, a real grinding wheel has waviness, run-out and protrusion height difference between a succeeding grain and a proceeding one. Considering these factors the formula is modified as follows.

$$d_g = 2a\frac{v_w}{v_s}\sqrt{\frac{d+w}{D_e}} + \delta \qquad (2)$$

w : run-out and/or wave amplitude of grinding wheel surface
δ : difference in protrusion height

This formula still gives only the grain depth of cut done by the succeeding abrasive grain of two adjoining grains. Furthermore, there is no criterion to give the value of spacing between active abrasive grains. To estimate the grain depth of cut generated by successive active abrasive grains on a periphery of a grinding wheel the protrusion height distribution of those successive active grains has to be taken into account. The peripheral envelope of the tops of successive active grains on a grinding wheel can be resolved into two components. One is the long component in wavelength to be equivalent to waviness. Another is the short one to be treated as the difference in protrusion height. The critical wavelength is six times the spacing between active abrasive grains(1). The spacing is defined as a mean value of spacing between successive grains that exist in the specific random distribution of protrusion heights. The maximum grain depth of cut is estimated as follows. Here d_g, w and a are given the new definition, and Δh is newly defined.

$$d_g = 2a\frac{v_w}{v_s}\sqrt{\frac{d+w}{D_e}} + \Delta h \qquad (3)$$

d_g : maximum grain depth of cut,
w : maximum runout and/or wave amplitude of grinding wheel surface_

a : mean value of spacing between successive cutting edges for Δh
Δh : protrusion height distribution of cutting grains

However, the spacing between the successive cutting grains, *a*, and the protrusion height distribution of grains, Δh, are to be evaluated experimentally. Since then, it is critically important how to observe the topography of abrasive grain tops.

3. In-situ 3-D observation of protrusion height distribution

For the estimation of the maximum grain depth of cut it is essential for observation of the topography of abrasive grain tops to be done on a grinding machine. If the observation is done outside the machine, the grinding wheel has to be trued and dressed after the wheel is mounted on the spindle again. The truing and dressing operations generate the entirely new distribution of protrusion height. This means that the observation system is required to be an 3-D observation system with high vertical and horizontal resolution and to function on a grinding machine. That system has two functions of both scanning a wheel surface on a grinding machine and detecting protrusion height of abrasive grains.

The possible constructions are listed in Table 1.

Table 1. Construction of in-situ 3-D observation system of protrusion height distribution

Functions	Methods
Detecting protrusion height	1. Stylus method 2. Non-contact method (optical probe)
Scanning a wheel surface	1. Scanning mechanism equipped for a observation system 2. Two axes positioning mechanism equipped for a grinding machine 3. Single axis driving mechanism equipped for a observation system plus single axis positioning mechanism equipped for a grinding machine

The in-situ 3-D observation system may be realized by coupling of these methods. A optical probe has advantage of no wear by probing a wheel surface, however disadvantage of low ability in probing a steep surface. Utilizing the positioning mechanism of a grinding machine for scanning is the best way to get the true topography of a grinding wheel surface, because protrusion height is observed from the reference of workpiece surface to be ground. However, it is worst in taking long time to scan. A scanning mechanism equipped for the observation system may be possible to be fast to scan because of small mass to be driven.

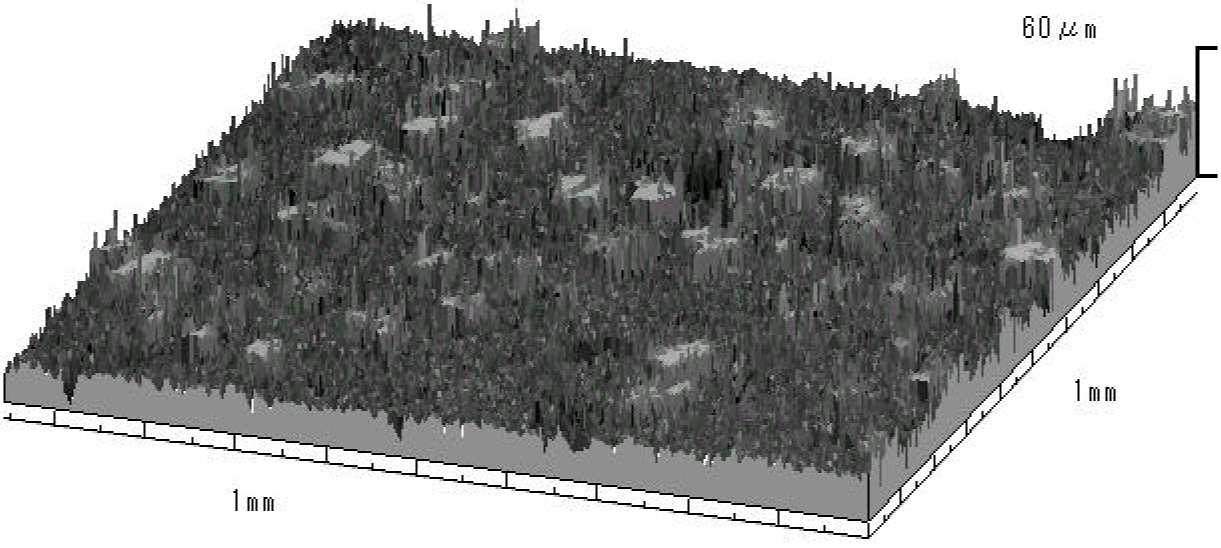


Fig.1 Topography of metal-bonded diamond wheel observed by optical system (grain size: #230)

In the present paper two combinations are tested. The first one was composed of an optical probe and 2-axes NC positioning system of a grinding machine with hydrostatic guideways. The optical probe has a beam of 2 µm in diameter, resolution of 0.1 µm and ability to probe surfaces inclined at less than 30 degree. The second one was the system equipped with a scanning mechanism. A 3-D surface profiler with a diamond stylus was utilized for 3-D observation of protrusion height distribution of active grains on a grinding wheel. The surface profiler which has been recently developed is compact enough to be set on the workpiece table of a grinding machine. It has a stylus of 5 μm in radius, resolution of 6 nm and scanning area of 1 mm by 1 mm.

Figure 1 is an example of the topography observed by the optical system. The target wheel is a metal-bonded diamond wheel with grain size of #230 and concentration of 100. The observed area is 1 mm by 1 mm. The optical system generated incorrect data of steep surfaces at the edge of abrasive grains. This caused low vertical resolution. This defect may be able to be improved by any kind of filtering process.

Figure 2 is topography observed by the 3-D surface profiler. The target wheel is same as the optical system. The wheel surface in 1 mm by 1 mm was scanned in horizontal resolution of 2 μm for about 5 minutes. The topography of the grinding wheel is clearly captured. Both size and protrusion height of individual grains and spacing between them can be recognized clearly enough to study machning mechanism.

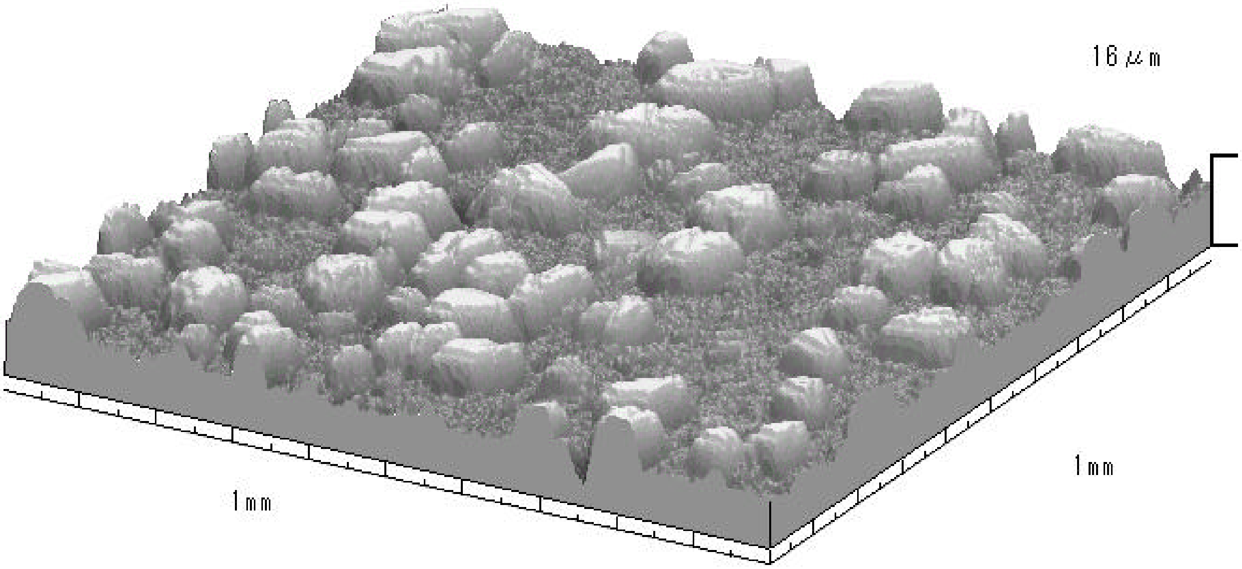


Fig.2 Topography of metal-bonded diamond wheel observed by 3-D surface profiler (grain size: #230)

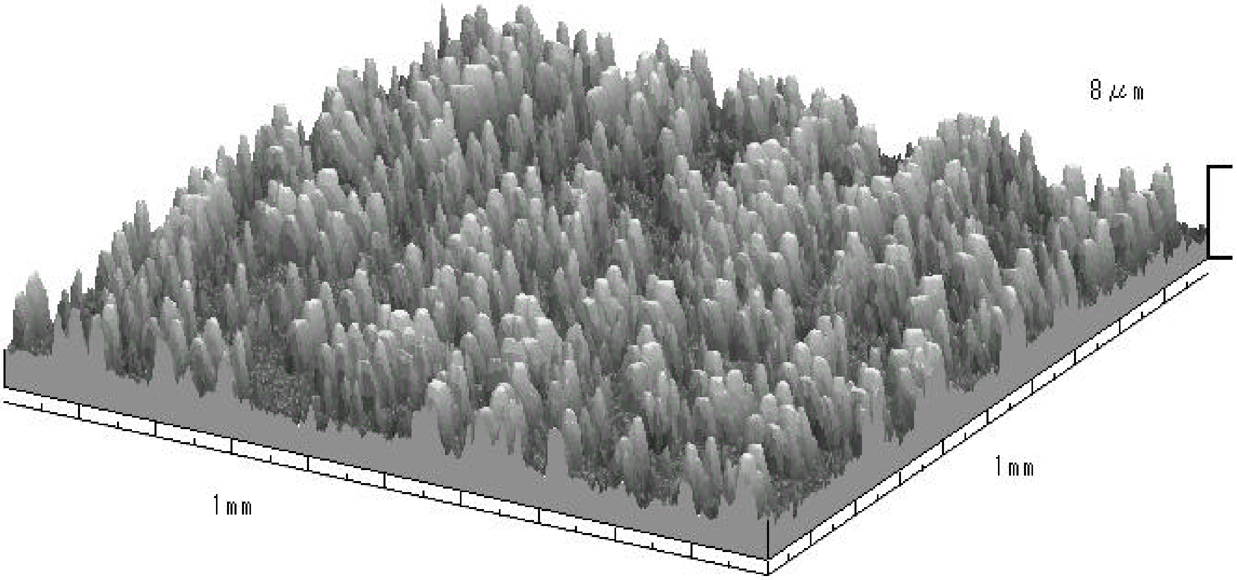


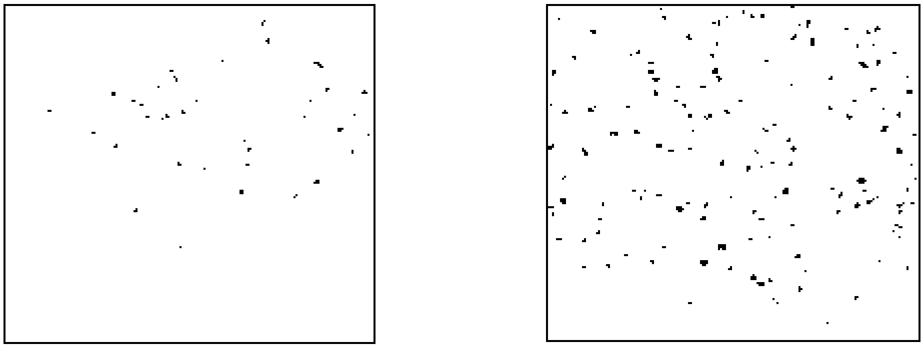
Fig.3 Topography of metal-bonded diamond wheel observed by 3-D surface profiler (grain size: #800)

4. Introduction of experimentally evaluated parameters to grain depth of cut

As mentioned above estimation of grain depth of cut requires introduction of experimentally evaluated parameters. These are a random distribution value of grain protrusion height and spacing between active grains derived from the distribution value. The topography data by in-situ 3-D observation can be analyzed to get those parameters.

Fig.3 is topography of a metal-bonded diamond wheel with grain size of #800 and concentration of 75. This was measured by the 3-D surface profiler. Individual grains of mean grain size of 20 μm in diameter can be recognized distinctly. For estimation of grain depth of cut the protrusion height of abrasive grains has to be evaluated from the highest top of grains, this means the closest cutting edge to a workpiece surface. Fig.4 shows the sliced surfaces of the topography shown in Fig.3 at a particular position downward from the highest top in the observed area. The slice level in Fig. 4 is 0.2 and 0.5 μm from the highest top. This kind of figure can be used to count the number of abrasive grains within the range from the highest top to the slice level, which corresponds to the random distribution of protrusion height of Δh. Fig.5 shows the number of active grains corresponding to Δh and from those number the spacing between active grains is derived. Fig.6 is a graph of the relationship between random distribution of protrusion height and spacing between grains. The spacing of six times the observed length is about 0.16 mm and Δh for this value of spacing is about 0.2 μm. Introducing these value, Δh of 0.2 μm and a of 0.16 mm to Equation 3 grain depth of cut in this case can be estimated to be about 0.2 μm.

Reference: (1) Kanai, A., Miyashita, M., Sato, M., Daito M., Proposal of High Productivity in Ductile Mode Grinding of Brittle Materials, Proc. of 1995 ASPE Annual Meeting



0.2 μm

0.5 μm

Fig.4 Grain distribution for slice level of 0.2 and 0.5 μm

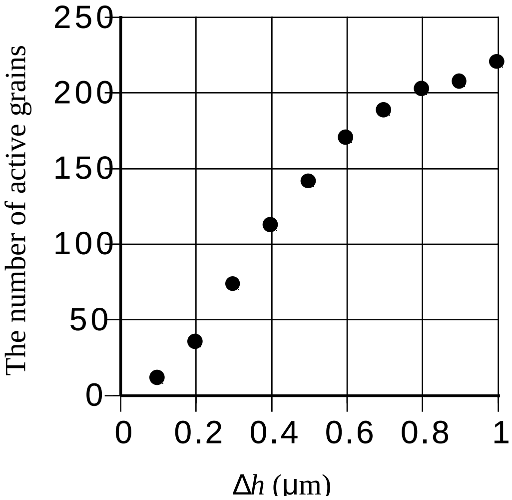


Fig.5 The number of active grain

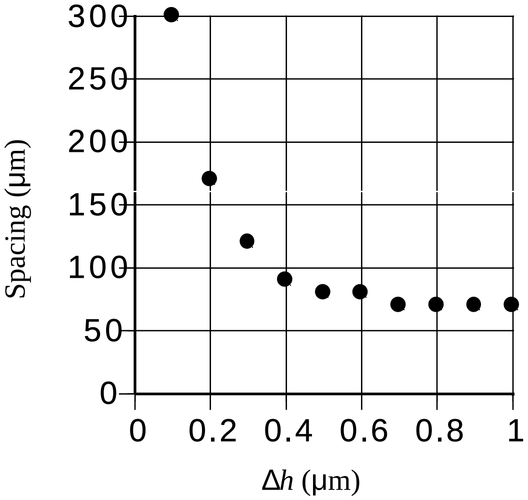


Fig.6 Spacing between active grains