Cutting Conditions of an Engineered Tool with the Ultrasonic Excitation

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1 Introduction
The laser machined diamond has many posts which correspond to the diamond grits on a grinding wheel. Post motion by ultrasonic excitation achieves an intermittent removal mechanism for a critical depth of cut and, as a result, depending on the number of posts, makes it possible to make a very large total depth of cut in brittle material machining.

2 An “Successive Grit Point Spacing” Model and Ultrasonic Vibration assisted Shear-mode Grinding
The main points demonstrated previously by our experimental results(1,2) are:
1) The grinding force showed almost no fluctuation. The reproducibility was as high as ± 2N. 2) Flat top grits were observed to cut material and found to be flat as if they had been abraded. 3) During the experiment no dressing was performed.
Distribution and resultant function (averaging effect) of abrasives have been explained statistically. Abrasives of grinding wheel surface have a Gaussian distribution (3).
The successive grit point spacing (p) is given by the following, \( P = \frac{w^2}{b} \), Here, \( w \) is the average grit point spacing and \( b \) is the average width of the groove.
When the wheel is excited with ultrasonic vibration of frequency \( f \) and amplitude \( a \), the motion of the grits can be expressed by a sinusoidal function and each grit has a phase shift of \((2\pi / \lambda) \cdot n \) • P, \( f(x) = a/2 \cdot \sin[(2\pi / \lambda) \cdot (x-n \cdot p)] \) Here, \( \lambda \) is the wavelength. Thus distributed grits are presumed to remove material at a depth lower than the critical depth of cut under certain machining conditions depending on the feed velocity and the ultrasonic frequency and amplitude.
Figure 1 shows the normal grinding force. When the silicon material is ground, chip-loading peculiar to the material accelerates an increase in the force.
However, when ultrasonic vibrations were applied, the grinding force remained almost constant. Although the cup-type grinding wheel had a greater contact area than the straight one, it was assumed that the cup-type grinding wheel used in this case allowed the inflow of relatively more grinding fluid. Furthermore, the problem of chip-loading could also be solved.

3 The Removal Mechanism and the Critical Depth of Cut of an Engineered Tool

To overcome the disadvantages of using a grinding wheel for ultrasonic vibration assisted grinding, that is, the excessive deviation of the continuous abrasive spacing from the average abrasive spacing, and the shedding, etc., an engineered tool chip (ET chip) was developed. This is composed of a large diamond chip (about 2mm×2mm square and about 0.5mm thick), which has been excimer laser-machined to leave 10 μm high posts that are about 3 to 5 μm square. Figure 2 shows details of the cutting edge of a single post. The ET chip characteristics are: a) high grain distribution density and b) uniform cutting edge; c) uniform grain projection height and d) uniform grain crystallographic orientation; and no contamination, because of no heavy metal.

The engineered tool has two parts, a rake surface and a flank one. The rake angle $\theta$ of the tool can be determined, so that the height difference of each adjacent post is lower than the critical depth of the cut $[d_c]$. 

![Figure 1](image1.png)

Fig. 1 Normal grinding force with the ultrasonic excitation.
The post motion is determined by the cutting speed $v$, ultrasonic frequency $f$, ultrasonic amplitude $a$, and the post pitch $P(s+w)$. Equations 1) and 2) give the post motions of the rake and flank surfaces, respectively. Intermittent removal is possible by designing the post pitch to have an adequate phase shift, as shown by the hatched part of Fig.3.

\[ f_{nr}(x) = n_r \times P(s+w) \times \tan \theta + \frac{a}{2} \times \sin \left[ \frac{2\pi}{\lambda} \times \left( x - n_r \times P(s+w) \right) \right] \]

\[ f_{nf}(x) = \frac{a}{2} \times \sin \left[ \frac{2\pi}{\lambda} \times \left( x + n_f \times P(s+w) \right) \right] \]

Here, $n_r, n_f$ are the numbers of posts on the rake and the flank surfaces, $P(s+w)$ is the Post pitch, $P_s$ is the post spacing. The total depth of cut $[dt]$ and the post height difference on
the rake surface (d) are given by the following:
\[ dt = a + nr \times dc \]  
\[ d = P(s + w) \times \tan(90 - \theta) \]

4. Conclusions
1) With tremendous cutting edges on the rake surface, that are aligned so that the vertical spacing is lower than the critical depth, making it possible to give a large total depth of cut.
2) The phase shift in the design of the cutting edge pitch means the cutting edges remove the material intermittently. This is expected to minimize cutting edge wear and subsurface damage.

References