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Surface generation in ultrasonic assisted face grinding

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Abstract

A kinematics analysis of the ultrasonic assisted face grinding is introduced. The surface morphology of the grinding wheel is defined based on the kinematics analysis. The maximum un-deformed chip thickness and the critical chip thickness are compared. The material removal mechanism is mainly ductile removal in this machining method. The hammering effect induced by the ultrasonic vibration on surface generation is also considered. Experimental results shows that increasing the feed rate in ultrasonic assisted face grinding leads to a better surface integrity.

Keywords: Ultrasonic assisted face grinding (UAFG), Ductile removal, Roughness

1. **Introduction**

Ultrasonic assisted grinding has attracted much attention in this recent years. Due to its positive effect on reducing the grinding force, thus tool wear ratio decreases and higher efficiency can be achieved [1]. Meanwhile, the face grinding shows great advantage in improve surface integrity due to its secondary removal [2]. This paper intends to reveal the mechanism of surface generation in UAFG through both theoretical analysis and experimental exploration.

2. Kinematics view of ultrasonic assisted face grinding

As shown in Fig. 1, ultrasonic assisted face grinding mainly consists of three movements. A rotating cup wheel is rotating and in the same time vibrating ultrasonically in the axial direction. In the meanwhile, an in-plane feed movement is applied.

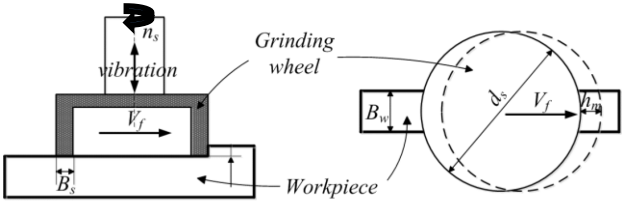

Figure 1. Illustration of ultrasonic assisted face grinding.

3. Wheel morphology definition

In the radial direction, the distance l_c between two times entering of a single grain along feed direction, shown as red line in Fig. 2(a), can be described as following:

$$l_c = \frac{60 v_f}{n_s}$$

v_f is the feed rate, ranging from 0.167mm/min to 7.5mm/min in this research. n_s is the rotating speed, setting constant, 6000rpm. Grain size of wheel is 46μm. Therefore, for the first material removal zone, only the outmost grain can be active.

To further investigate the surface generation, the wheel morphology should be defined more closely to the actual conditions. However, due to the random distribution of the grains, some assumptions are necessary to be made as follows:

1) The diamond abrasive particles are assumed to be rigid octahedral shape, which is more accurate model in this research. The edge length and semi angle are symbolled as S_a and β [3].

2) Along the peripheral direction, the cutting point angle between the adjacent grains is assumed to be uniform, the distance L_l and angle θ_l can be calculated by:

$$L_l = [\frac{100(\frac{\sqrt{2}}{3}){S_a}^3 \rho}{0.88 C_a}]^{1/3}$$
$$\theta_l = 2L_l/d_s$$

In these two equations, ρ is the density of diamond, C_a is the abrasive concentration of grinding wheel, its value is 100.

3) As to the protrusion height, either in the axial direction or in the radial direction, the protrusion heights of all grains are stochastically located.

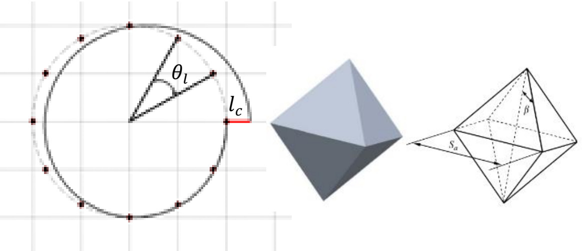

Figure 2. Illustration of abrasive particle.

4. The maximum un-deformed chip thickness and critical chip thickness

The maximum un-deformed chip thickness h_m, shown in Fig. 1in the feed direction can be described as the following:

$$h_m = k\theta_l \frac{30 v_f}{\pi n}$$

Considering the protrusion height in the radial direction, roughly, $k > 2$. According to Bifano [4], the critical chip thickness d_c can be expressed as:

$$d_c = 0.15(\frac{E}{H})(\frac{K_c}{H})^2$$

E is Elastic Modulus, H is Hardness and K_c is the fracture toughness of the workpiece material. In this research, 3Y-TZP blocks ($B_w = 5mm$) were used, starting powder TZ-3Y-E (Tosoh, Japan, with 0.25 wt. % alumina) were cold isostatic pressed (CIP) at 200MPa and sintered in air for 2h at 1450℃. Mechanical properties of this material are list in table 1.

Table 1. Mechanical properties of 3Y-TZP.

Fracture toughness [MPa $\cdot$m$^{1/2}$]	Hardness [kg/mm^2]	E-Modulus [GPa]
4.1$\pm$0.1	1304 ± 5	210

The calculated results against feed rate are shown in Fig. 3. It can be interpreted that the main material removal mechanism in this case is ductile removal except that very few abnormal protruding grains. This result is in accordance with literature [5].

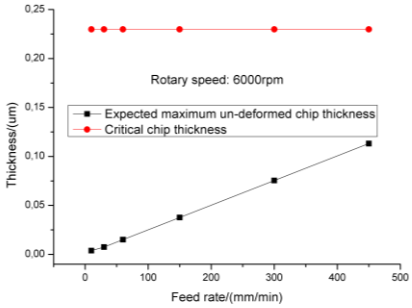

Figure 3. h_m and d_c against feed rate.

5. Surface generation analysis in UAFG

As to the ductile removal, the scallop height shown in fig. 4 plays an important role on the final surface roughness. It can be calculated by this equation:

$$h_s = \frac{h_m}{2} = k\theta_l \frac{15v_f}{\pi n}$$

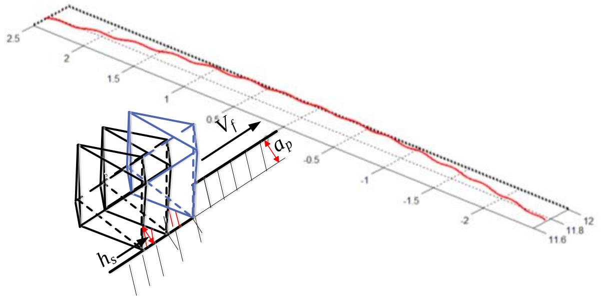

Figure 4. Scallop height and vibration cycles along width of block.

A bigger feed rate leads to a large scallop height. So the number of vibration cycles and wave valleys per unit area N_a and per unit length along feed direction N_l are critical.

$$N_a = 2kf\sin^{-1}(\frac{B_w}{d_s})/\theta_l v_f B_w$$

$$N_l = \sqrt{N_a}$$

f is the frequency of ultrasonic vibration, B_w is the width of the workpiece. Increasing the feed rate results in fewer valleys, so it will definitely reduce the roughness values.

5. Surface generation analysis in UAFG

Grinding tests were carried out on a DMG Sauer® linear 20 micro-milling machine. To obtain the roughness features, a Talysurf 120L Surface analyser (Taylor Hobson®) was applied. The surface morphologies was investigated by a SEM (Philips/FEI® XL-30FEG).

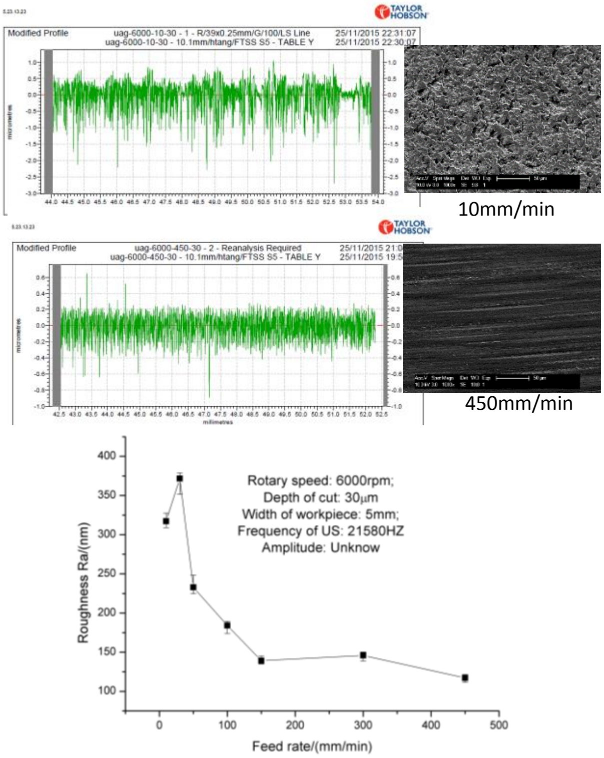

Figure 5. Surface morphologies and roughness against feed rate.

The surfaces obtained from 10mm/min and 450mm/min show apparent difference in both surface roughness and morphology. Much more valleys and dots can be seen when small feed rate is applied. It is different from conventional grinding, the measured surface roughness decreases along with the increase of the feed rate.

6. Conclusion

This paper intends to explain the surface generation in UAFG. A better surface can be obtained by applying large feed rates. Vibration plays a dominant effect on the surface generation. However, the material removal mechanism in this processing method still need to be further studied in both theoretical analysis and experimental verification.

References

[1] D. Bhaduri, SL. Soo et al, 2013, ultrasonic assisted creep feed grinding of Inconel 718, Procedia CIRP, 615-620.

[2] D.J. Stephenon, D. Veselovac, S, Manley, J. Corbett, 2001, Ultra-precision grinding of hard steels, Precision Engineering, 25, 336-345.

[3] D. Liu, W.L. Cong, Z.J. Pei, Y.Tang, 2012, A cutting force model for rotary ultrasonic machining of brittle materials, J. Mach. Tool. Manu., 52, 77-84.

[4] T.G. Bifano, T.A. Dow, R.O. Scattergood, 1991, Ductile-regime grinding: A new technology for machining brittle materials, J. Eng. Ind., 113, 184-189.

[5] M. Rabiey, Nicolas Jochum, Fredy Kuster. 2013, High performance grinding of Zirconium Oxide (ZrO$_2$) using hybrid bond diamond tools, CIRP ANN-Manuf. Tech., 62, 343-346.