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Study on the Material Removal Function of Ultrasonic-assisted Abrasive Flow Polishing Sapphire

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ABSTRACT

As a kind of hard and brittle material, the removal method of sapphire is mainly deformation removal with the scour of abrasive flow, which means that machined surface deform with the scour of abrasive flow, if the deformation is large enough, there could be crack and exfoliation on the material surface or subsurface to achieve the removal of material. Based on the knowledge of contact mechanics, this article deduces the material removal function under single abrasive, abrasive flow and ultrasonic vibration, and finds that it is a favor to polishing under assist of ultrasonic vibration.

INTRODUCTION

The principle of ultrasonic-assisted abrasive flow polishing sapphire[1,2] is that: when polishing liquid scour the surface of sapphire surface, the abrasive in polishing liquid impact the surface of the workpiece and there is extrusion on the surface of workpiece which results in minim plastic deformation that makes the surface more smooth. Towards sapphire, hard and brittle material, when deformation is large enough, there could be crack and exfoliation on the material surface or subsurface. At the same time, imposing ultrasonic vibration on the workpiece can

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improve chances of impact between abrasive and workpiece, and it also improve the polishing efficiency. Build models according to the above conclusions respectively, and build the following hypothesis:1) A certain one abrasive act on the surface directly, and there is no energy exchange with other abrasive;2) The medium of polishing liquid is homogeneous;3) Ignore the crack on the surface caused by impact.

The Material Removal Function of Single Abrasive

When polishing liquid scour surface of workpiece, it impact several abrasives so that the process is complicated. Research the material removal function of single abrasive firstly to simplify the material removal model[3]. According to the relative knowledge of contact mechanics[4], build the following model, if the radius and the mass of the abrasive are R_1 and m_1 respectively, and it impacts on the workpiece that the radius and the mass of which are R_2 and m_2 respectively. Suppose the relative displacement is δ, then the relative velocity is:

$$\frac{d\delta}{dt} = v_2 - v_1 \tag{1}$$

If the force between them is $P(t)$ at any instant, then:

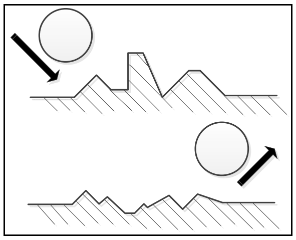
$$\begin{cases} P = m_1 \frac{dv_1}{dt} = -m_2 \frac{dv_2}{dt} \\ -\frac{m_1+m_2}{m_1 m_2} P = \frac{d}{dt}(v_2 - v_1) = \frac{d^2\delta}{dt^2} \end{cases} \tag{2}$$

According to static elastic contact:

$$\begin{cases} P = \frac{4}{3} R^{\frac{1}{2}} E^* \delta^{\frac{3}{2}} = K\delta^{\frac{3}{2}} \\ \frac{1}{E^*} = \frac{1-v_1^2}{E_1} + \frac{1-v_2^2}{E_2} \\ m\frac{d^2\delta}{dt^2} = -K\delta^{\frac{3}{2}} \\ \frac{1}{2}\left[V^2 - \left(\frac{d\delta}{dt}\right)^2\right] = \frac{2}{5}\frac{K}{m}\delta^{\frac{5}{2}} \end{cases} \tag{3}$$

where, $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$, $\frac{1}{m} = \frac{1}{m_1} + \frac{1}{m_2}$.When the two get close, the velocity isV. When δ reaches maximum, $d\delta/dt = 0$, then, the maximum deformation can be got :

$$\delta = \left(\frac{5mV^2}{4K}\right)^{\frac{2}{5}} = \left(\frac{15mV^2}{16R^{\frac{1}{2}}E^*}\right)^{\frac{2}{5}} \tag{4}$$



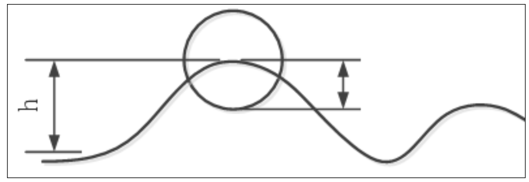


Figure 1. Principle of deformation removal. Figure 2. Sketch of the abrasive impacting surface.

The volume under this deformation can be got according to the maximum deformation, which is the maximum removal amount:

$$MR = \pi\delta^2\left(R - \frac{\delta}{3}\right) \quad (5)$$

It is know that $m=\frac{4}{3}\pi\rho R^3$, so the relationship between the removal amount of material and velocity and radius of abrasive can be got:

$$MR = \pi\left(\frac{5\pi\rho R^{\frac{5}{2}}V^2}{4E^*}\right)^{\frac{4}{5}}\left[R-\left(\frac{5\pi\rho R^{\frac{5}{2}}V^2}{4E^*}\right)^{\frac{2}{5}}/3\right] \quad (6)$$

It can be seen according these relational formulas that the function of material removal amount of single abrasive is relative to the radius and velocity of polishing abrasive. The velocity of abrasive can promote the material removal amount, which means that the material removal amount increases with the increase of the velocity of abrasive; but the effect of radius is not obvious, because there is only few increase of removal amount with the increase of radius.

The Material Removal Amount Function of Abrasive Flow

Deduce the material removal function of abrasive flow based on that of single abrasive. At the same point on the workpiece, when abrasive impacts the workpiece again, it is an impact based on the first impact, the model of which is the following figure. And because the curvature radius of workpiece is far larger than that of abrasive, workpiece can be simplified to be plane. Then, subtracting the removal amount of the first time from the total removal amount is that of the second time.

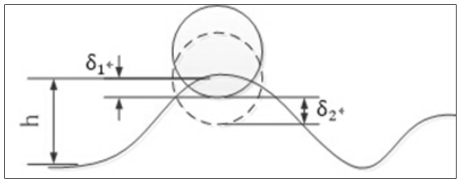


Figure 4. The second time that abrasive impacts the surface of workpiece.

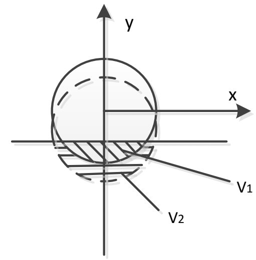


Figure 5. The ideal model.

At the same point, when abrasive impacts workpiece again, the material removal amount is:

$$\begin{cases} V_1 = \pi\, \delta_1{}^2 \left(R - \frac{\delta_1}{3}\right) \\ V_1 + V_2 = \pi(\delta_1+\delta_2)^2 \left(R - \frac{\delta_1+\delta_2}{3}\right) \\ V_2 = \pi(\delta_1+\delta_2)^2 \left(R - \frac{\delta_1+\delta_2}{3}\right) - \pi\, \delta_1{}^2 \left(R - \frac{\delta_1}{3}\right) \end{cases} \quad (7)$$

Deduce according to above formulas, the removal amount of some particle that be impacted for N times can be got:

$$V_n = \pi(\delta_n + \cdots + \delta_0)^2 \left(R - \frac{\delta_{n+1} + \delta_n + \cdots + \delta_0}{3}\right) - \pi(\delta_{n-1} + \cdots + \delta_0)^2 \left(R - \frac{\delta_{n-1} + \cdots + \delta_0}{3}\right) \quad (8)$$

Supposed that at some moment, there are A abrasives flow through the micro cavity and impact the surface, in these A particles, there are A_1 particles that are impactedfor the first time, and there are A_N particles that are impacted for N times.Then superimposed the removal amount of every impacted particle at this moment, the total removal amount can be got:

$$MR = A_1 V_1 + A_2 V_2 + \cdots + A_N V_N \quad (9)$$

Where, $A = A_1 + A_2 + \cdots + A_N$.

The Material Removal Function Under Ultrasonic Vibration

When impose ultrasonic vibration on workpiece, there is relative motion between workpiece and abrasive, removal function under vibration can be got through relative velocity.

$$\begin{cases} u = 2\pi f A \sin 2\pi ft \\ v' = v - u = v - 2\pi f A \sin 2\pi ft \\ V' = \pi \left(\frac{5\pi\rho R^{\frac{3}{2}} v'^2}{4E^*} \right)^{\frac{4}{5}} \left[R - \frac{1}{3} \left(\frac{5\pi\rho R^{\frac{3}{2}} v'^2}{4E^*} \right)^{\frac{2}{5}} \right] \end{cases} \quad (10)$$

where, u is the vibration velocity, v' is relative velocity between polishing abrasive and workpiece.

The removal amount under abrasive of uniform velocity, ultrasonic vibration and no ultrasonic vibration in a while can also be got. As time passed, there is no change on the removal amount if there is no vibration. Theoretical removal amount is 1.7264 according to calculations, but the removal amount under ultrasonic vibration is higher than 1.7264 with micro volatility, and there is no great change amplitude. This illustrates that the condition of ultrasonic vibration can improve material efficiency.

CONCLUSIONS

Firstly, the article explores interactive approach between polishing abrasive and workpiece and principle of material removal. And the article also deduces removal function of single abrasive based on the mothed of removing surface material of sapphire and contact mechanics, removal function under abrasive flow and ultrasonic vibration. And it is also can be seen the effect of twice deformation depths of abrasive flow on material removal amount. Through removal amount function under ultrasonic vibration, it can be seen that ultrasonic vibration can improve polishing effect.

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