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CVD Diamond Film Polishing Method Based on Accelerant Theory and Uniformity Analysis

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Abstract: The ultra-precision machining of CVD diamond films is one of the key technologies to expand the application of diamond films. This paper presents a new CVD diamond film polishing method - based on the accelerant theory. The principle is analyzed first. It makes use of transition metal as accelerant to reduce the activation energy required for graphitization, improve reaction rate of graphitization and promote the realization of diamond removal mechanism. Then, the accelerant polishing experimental system is established. In order to explore the influence of the machining speed ratio (k) and eccentric distance (e) on grinding quality, the grinding trajectory simulation analysis is adopted to the CVD diamond samples. The results show when is the motion direction of w_1 is same as the w_2, CVD diamond sample processing has good uniformity and efficiency as e = 95 mm, k = 0.6; When is the motion direction of w_1 is opposite to the w_2, CVD diamond sample processing has good uniformity and efficiency as e = 95 mm, k = 0.35. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: CVD diamond film, Accelerant theory, Machining speed, Eccentric distance, Grinding quality.

1. Introduction

Diamond is one of the brilliant materials in this world because of its outstanding physical property. The advent of CVD diamond makes the performance of diamonds fully exploited. Materials scientists assert that CVD diamond will become the mainstream of the development of diamond materials in the future. However, CVD diamond film is holocrystalline polycrystalline film currently and the roughness value (Ra) of scraggly growth surface is several microns to tens of microns generally. So, the CVD diamond film cannot be applied directly in many cases [1]. The thin, high uniformity and high integrity of electronic information materials propose a higher require for CVD diamond film, in the other hand, the polishing of CVD diamond film exists the problems of low efficiency, high cost, complex process and others at the present stage, Therefore, ultra-precision machining of CVD diamond films has become one of the key technologies to expand the application of diamond film [2-5].

CVD diamond polishing methods in the world are following: 1) Mechanical polishing, 2) Thermo-chemical polishing, 3) Chemical assisted polishing, 4) Laser polishing 5) Ion beam polishing and so on. Different methods have their advantages and disadvantages. The methods that often be used now are mechanical polishing, thermo-chemical polishing and chemical assisted polishing. Because of the impact of the equipment costs, processing efficiency, other polishing methods are not yet all-pervading. What is more, most of these methods are still in the research stage [6-9]. A. M. Zaitsev and et al [10] conduct a diamond film polishing study by a steel plate with a vibration device at a high temperature and achieve a good polishing effect. Y. J. Sun and et al [11] conduct a diamond film polishing study by a molten Ce at a low temperature and think that method has a high polishing rate, and heat treatment does not affect the surface structure of diamond. C. Y. Wang and et al [12] conduct a study of the method of chemical assisted polishing, using a mixture of LiNO3 and KNO_3 as oxidants to improve the mechanical polishing efficiency and precision. C. J. Tang and et al [13] conduct a grinding and polishing by using two diamond films in a certain pressure and rate of relative movement, which diamond film removal rate of up to 10 um/h. This method is simple and convenient. The rate of polishing is fast, which is suitable for rough machining.

This paper proposed a method of CVD diamond polishing based on accelerant theory. This method based on the principle of diamond graphitization and using the iron, nickel, cobalt and other transition metal's catalysis in the process can effectively reduce the activation energy needed for the graphitization of diamond, and formed the graphite and amorphous carbon that is easy for grinding, at the same time, promote the diffusion of carbon atoms in the metal and oxidation in the air, thereby, improve the efficiency of material removal. Then, the accelerant polishing experimental system is established. In order to explore the influence of the machining speed and eccentric distance on grinding quality, the grinding trajectory simulation analysis is adopted to the CVD diamond samples. The results show when is the motion direction of w_1 is same as the w_2, CVD diamond sample processing has good uniformity and efficiency as *e* = 95 mm, *k* = 0.6; When is the motion direction of w_1 is opposite to the w_2, CVD diamond sample processing has good uniformity and efficiency as *e* = 95 mm, *k* = 0.35.

2. Analysis of Accelerant Theory

The removal mechanism of polishing method based on the accelerant theory is mainly founded on the following aspects: transition metal graphitization under the action of accelerant theory, carbon atoms diffusion of in metal, oxidation in air and mechanical grinding of diamond grinding wheel.

The essence of graphitization of diamond is the process that sp3 bond of diamond is broken up and generate other allotrope under the action of thermal field.

Analysis of chemical potential energy of graphitization of diamond is introduced by Fig. 1 [14].

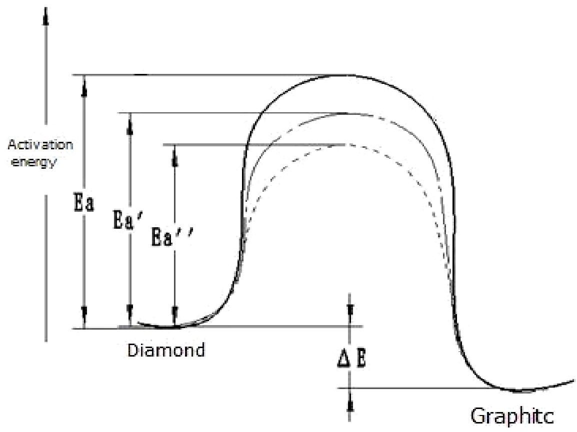


Fig. 1. Activation energy in graphitization of diamond.

It can be seen, the chemical potential energy of graphite is lower than diamond, but in order to achieve the excitation potential energy C of graphitization of diamond, it must absorb corresponding activation energy Ea. Under the catalytic action of transition metal (Fe, Ni, Co etc.), especially the combined action of transition metal and oxygen (O_2), the excitation potential energy is decreased obviously. The graphitization of diamond would be achieve just need a little of activation energy Ea [15].

According Arrhenius equation, shown in formula 1, the value of activation energy is inversely proportional to reaction rate. The reaction rate will increase with the reducing of activation energy Ea. Transition metal can reduce the demand of activation energy and promote the reaction rate in graphitization of diamond.

$$k = k_0 e^{-\frac{E_a}{RT}}, \tag{1}$$

where k_0 is the constant, E_a is the activation energy, R is the gas constant, T is the absolute temperature.

Carbon atoms will spread to metal due to the density difference when diamond contact with metal. According to Fick first law, shown in formula 2, the concentration distribution of carbon atom in the metal can be known.

$$J = -AD\frac{\partial c}{\partial z}, \tag{2}$$

where A is the diffused sectional area, D is the diffusivity, $\frac{\partial c}{\partial z}$ is the diffused concentration difference.

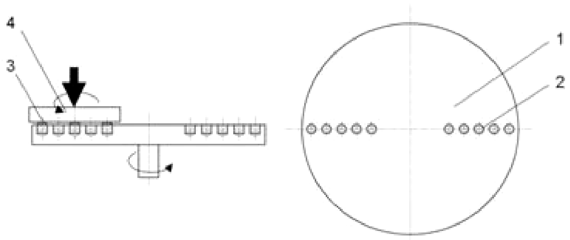
When the area A and concentration difference is constant, carbon atoms has a higher diffusivity D in the diffusion of transition metal, there into, the carbon atoms of graphite have higher the diffusion rate than diamond, so that, the graphitization can promote the diffusion rate of carbon, as well as the efficiency of dislodging diamond to some extent.

The essence of graphitization of diamond is to reduce the activation energy and promote the reaction rate of graphitization of diamond by transition metal which will promote the removal mechanism of diamond.

3. Experiment Research

Experiment program is shown in Fig. 2. Grinding plate that made by cast iron is used for polishing plays the role of accelerant. Meanwhile, a straight line where the diameter locates distributes symmetrical five diamond grinding wheels; those wheels play the role of grinding. Processing samples (CVD diamond films) are uniformly distributed in the lower surface of the planet wheel. They contact with grinding plate fully under load. When the grinding plate moves, samples have relative moves with it driven by the planet wheel. It will produce a lot of heat between the sample and grinding plate due to friction. Because of the accelerant of iron (Fe) in the grinding plate, it can realize the graphitization of the samples under low conditions and form the low hardness carbon that easy for grinding, however, the diamond wheels distributing in the surface of the grinding plate play the role of grinding and polish the samples.

This experiment uses nano-max polishing machine, which speed range is 0-140 r/min. The grinding plate is made by cast iron, which consists of (2.5-3.0) %C, (2.0-3.0) %Si, (0.5-0.7) %Mn, <0.0.8 %P, <0.02 %S, (0.03-0.07) %Mg. The particle size of 500 monocrystalline diamond is used as the abrasive of diamond wheel. The resin is used as binder.



1 – Grinding plate, 2 – Diamond wheels, 3 – Processing sample, 4 – Planet wheel.

Fig. 2. Polishing sketch map based on accelerant theory.

4. Simulation of Trajectory Uniformity

The catalysis of samples is directly proportional to the speed of polishing disk, but diamond grinding wheel distribute evenly in the polishing disk circumference and processing samples distribute evenly in the planet wheel circumference. By analyzing the speed ratio and eccentricity between polishing disk and planet wheel, the optimal process parameters can be obtained. On this account, the efficiency and homogeneity of CVD diamond film polishing can be enhanced.

4.1. Mathematical Model of the Polishing Trajectory

In order to analyze trajectory of any point in the work piece, it is need to establish three coordinate systems.

Coordinate system 1: static coordinate system, the Center is in o_1, $\sigma_1 = [o_1, x_1, y_1]$;

Coordinate system 2: Moving coordinate system with a rotate velocity of w_2, which center is in O_2, $\sigma_2 = [o_2, x_2, y_2]$;

Coordinate system 3: Moving coordinate system with a rotate velocity of w_1, which Center is in $O_1, \sigma_3 = [o_3, x_3, y_3]$;

Taking a point H in the circumference of workpiece plate, Point H rotates with workpiece plate at the same speed, the angular velocity is w_2, and the distance between o_2 and point H is r, and the angle between x axis in the positive direction is θ, shown in Fig. 3.

Equation of motion of point H in σ_2 is:

$$\begin{cases} x_2 = r\cos(w_2 t + \theta) \\ y_2 = r\sin(w_2 t + \theta) \end{cases}, \tag{3}$$

Translation to the σ_1 coordinate system:

$$\begin{bmatrix} x_1 \\ y_1 \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & e \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_2 \\ y_2 \\ 1 \end{bmatrix}, \tag{4}$$

In equation (3) and (4), $(x_1,\ y_1,\ 1)$ is the new coordinate after translation from $(x_2,\ y_2,\ 1)$.

Coordinate rotation transformation formula is:

$$\begin{bmatrix} x' \\ y' \\ 1 \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix}, \tag{5}$$

The original coordinate $(x,\ y,\ 1)$ rotate about the origin of clockwise with $w_1 t$, and get:

$$\begin{bmatrix} x_3 \\ y_3 \\ 1 \end{bmatrix} = \begin{bmatrix} \cos w_1 t & \sin w_1 t & 0 \\ -\sin w_1 t & \cos w_1 t & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_1 \\ y_1 \\ 1 \end{bmatrix}, \tag{6}$$

where $(x_3,\ y_3,\ 1)$ is the new coordinate after translation from $(x_1,\ y_1,\ 1)$, shown in Fig. 4.

According to the coordinate transformation of physical meaning, it can get:

$$\begin{cases} x_3 = r\cos(\theta - w_1 t + w_2 t) + e\cos w_1 t \\ y_3 = r\sin(\theta - w_1 t + w_2 t) + e\sin w_1 t \end{cases}, \qquad (7)$$

This is the trajectory equation of arbitrary point in rotating plate.

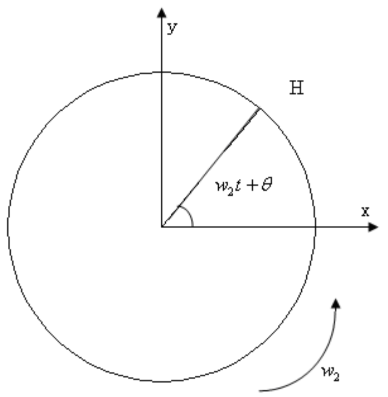


Fig. 3. Trajectory coordinate system 1.

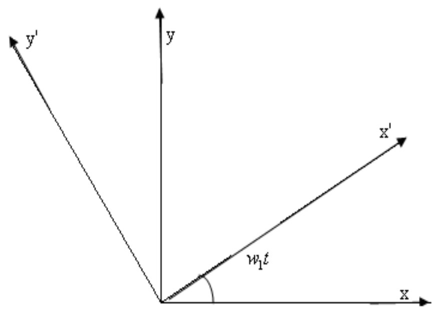
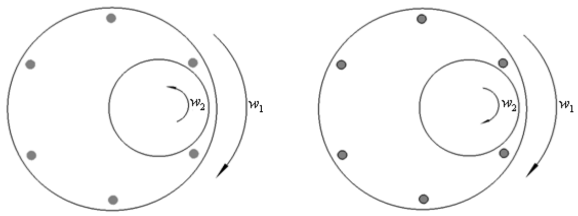


Fig. 4. Trajectory coordinate system 2.

4.2. Defines of Kinematics Parameter

The analysis of abrasive disk and planet wheel is shown in Fig. 5. The rotate speed of abrasive disk and planet wheel is w_1 and w_2. Because there is only some position has diamond grinding, therefore, in the process of polishing, CVD diamond sample is part-time in the catalytic state, some time in the grinding state. It requires an appropriate parameter to promote polishing more efficient and homogeneous.

In this study, the known parameters are position and diameter of diamond wheel on abrasive disk and the position of CVD diamond films, setting a size of planet wheel, we can get the best efficiency and homogeneity when diamond wheel is cutting samples by through the rotational speed ratio k ($k = \frac{w_2}{w_1}$) and eccentricity e. When the best rotational speed ratio k and eccentricity e are got, the best size of planet wheel can be achieved while take radius of planet wheel as a variable.



(a) Opposite motion direction (b) Same motion direction

Fig. 5. Rotate speed analysis of planet wheel and grinding plate.

4.3. Simulation Process

Based on the analysis above, the diamond films motion track of accelerant grinding method is simulated by MATLAB. The flow chart is shown in Fig. 6. 1) Setting the motion parameters e, w_1, w_2, r; 2) Calculating the times of grinding of each work piece according to (3-7); 3) Plotting the simulation diagram of grinding times; 4) Analyzing the consequence.

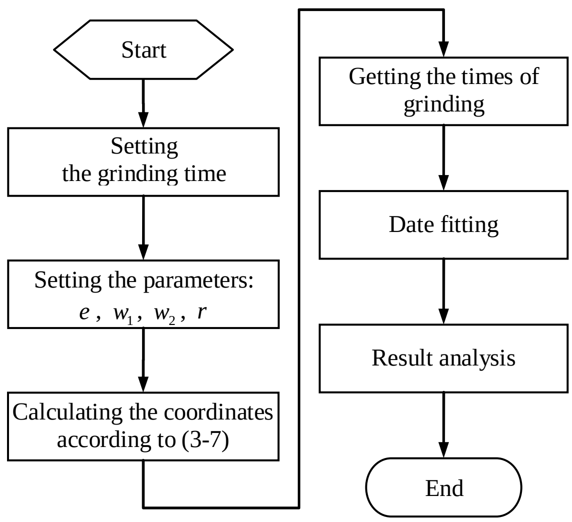


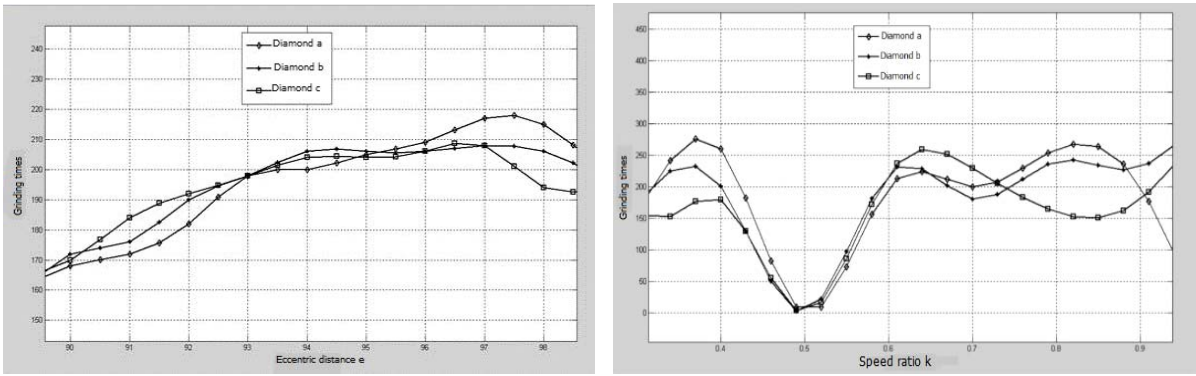
Fig. 6. Simulation flowchart.

5. Results Analysis of Simulation

When w_1 and w_2 are in the same movement direction, the impact of parameter e on the processing uniformity is calculated. In addition, the value of e is in the range of 81-100 mm. The frequency that samples are grinded by diamond wheels is simulated as the step length is 1 mm when $t = 200\pi$, that is, the grinding numbers will add one when the diamond goes through the wheel every time. Then fitting the data, the results are shown in Fig. 7(a). It can be seen that when $e = 96$, polishing degree of three diamonds is in a good consistency. Polishing efficiency is also high.

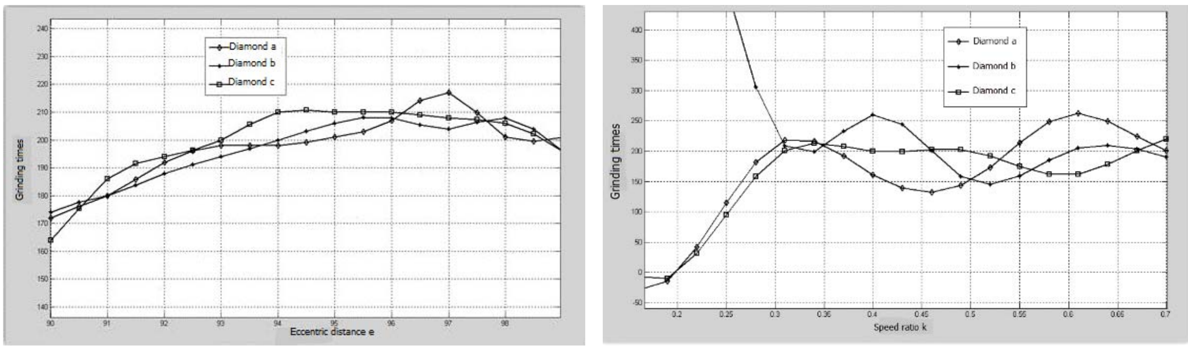
The impact of parameter k on the processing uniformity is calculated. In addition, the value of k is in the range of 0.1-2. The frequency that samples are grinded by diamond wheels is simulated as the step length is 0.1 when $t = 200\pi$, that is, the grinding numbers will add one when the diamond goes through the wheel every time. Then fitting the data, the results are shown in Fig. 7(b). It can be seen that when $k = 0.6$, polishing degree of three diamonds is in a good consistency. Polishing efficiency is also high.

When w_1 and w_2 are in the opposite movement direction, the simulation is carried out in the same way as above. The results are shown in Fig. 8. It can be seen that when $e = 96$ and $k = 0.35$, polishing degree of three diamonds is in a good consistency.



(a) Impact of eccentric on uniformity (b) Impact of speed ratio on uniformity

Fig. 7. Comparison of simulation results.



(a) Impact of eccentric on uniformity (b) Impact of speed ratio on uniformity

Fig. 8. Comparison of simulation results.

6. Conclusion

1) CVD diamond Polishing based on accelerant theory can realize the diamond's graphitization under a low situation. It is a convenient and efficient grinding method. Relating to thermo-chemical polishing and chemical assisted polishing, the method in this paper does not need the environment of high temperature, vacuum and hydrogen. The graphitization of CVD diamond film can be realized in normal situation.

2) Polishing system of CVD diamond based on accelerant theory can be achieved by rebuild abrasive disk and planet wheel or resetting process parameters, which can reduce the cost.

3) The influence of the machining speed and eccentric distance on grinding quality is researched through simulation. In order to get good uniformity and processing efficiency, when the movement direction of w_1 and w_2 is the same, $e = 95mm, k = 0.6$ should be chosen; When the movement direction of w_1 and w_2 is the contrary, $e = 95mm, k = 0.35$ should be chosen.

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