Research on preparation of HFCVD diamond coated milling cutter and stone cutting performance

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Abstract. The study is on the properties of diamond coating prepared on milling cutter and its effect on the cutting performance of stone. The method of hot filament chemical vapour deposition HFCVD was used to deposit diamond film coatings on the surface of the cemented carbide milling cutter. The surface morphology, composition and grain orientation of the diamond films on the cemented carbide milling cutter were analysed by using scanning electron microscopy, Raman spectroscopy and X-ray diffraction; the prepared diamond coated milling cutter was used to process the stone experiment, and the cutting performance of the diamond layer cutter with different carbon sources was analysed. The prepared diamond-coated cutter has a small diamond grain size on the surface, typically <111> crystal face disappears, and the grain orientation presents nano-crystalline diamond. Compared to the uncoated cutter, the surface roughness decreases. After coating, the diamond coating on the surface of the cutter did not show obvious shedding, and the amount of wear on the back face of the uncoated cutter was consistent.

1. Introduction
Chemical vapor deposition diamond films have excellent properties such as hardness, high modulus of elasticity, low coefficient of friction, high thermal conductivity, good self-lubrication, and chemical stability that are very close to that of natural diamonds. The field of molds and wear-resistant devices has broad application prospects. With the continuous improvement of people's material and cultural level, people's demand for stone art products is also growing. Stone is a typical hard-brittle material. The commonly used diamond sintered cutters are not suitable for high-precision machining of the stone because they cannot ensure the machining accuracy. The electroplating tools cannot be used for a long time due to excessive wear. The CVD diamond-coated tool is a new type of cutting tool. On the basis of the cemented carbide forming tool, a layer of diamond coating is deposited on the surface of the tool by chemical vapor deposition to improve the wear resistance and surface hardness of the tool. After the coating of the tool, the machining accuracy can be significantly improved, and the service life of the tool is extended to a certain extent, thereby reducing the processing cost and improving the processing efficiency.

1.1. Substrate surface pre-treatment method
The test adopts hot wire chemical vapour deposition method with methane as carbon source to deposit diamond coating on YG6 cemented carbide ball end mills. Prior to deposition, pre-treatment of the
cutter surface was performed. The specific process of surface pre-treatment is as follows: First, ultrasonic cleaning in acetone solution, deionized water and ethanol solution for 5 minutes to remove impurities such as oil stains on the substrate surface, followed by alkali solution (solution mass ratio KOH:K3(Fe(CN)6 ):H2O=1:1:20). Etching for 10 minutes in order to remove tungsten carbide grains from the substrate and expose Co on the surface of the substrate. Then, use an acid solution (the volume ratio of the solution is H2SO4:H2O2=1: 10) Etching for 1 minute to remove Co from the surface of the substrate and ultrasonically sonicating in acetone solution, deionized water, and ethanol solution for 5 minutes to remove residual acid and alkali solution from the surface of the substrate and put it into a diamond suspension solution. Crystallization will take place for 30 minutes. A diamond-coated tool was then prepared on the HFCVD apparatus using the deposition process parameters in table 1.

| Temperature (℃) | Pressure (Mpa) | H2 (sccm) | CH4 (sccm) | growth time (h) |
|-----------------|----------------|-----------|------------|-----------------|
| 850-900         | 5              | 800       | 8          | 10              |

1.2. Preparation and characterization of diamond-coated tools
Scanning electron microscopy (SEM) was used to observe the surface morphology of the diamond-coated tool. The Raman spectrometer was used to analyze the surface composition of the diamond-coated tool. The X-ray diffractometer was used to study the grain orientation of the diamond-coated tool.

2. Test results and analysis

2.1. Diamond coated tool surface morphology

![Figure 1](image1.png)

**Figure 1.** Diamond coated cutting tools surface morphologies of the as-deposited films.

Figure 1 shows the surface morphology of the diamond film of the cutter. When the methane concentration is 1%, the grain size of the film is in the order of micrometer, and the structure between the diamond grains is dense. Although the grain size is different, the exposed crystal planes are typical. 111> crystal surface, exposed crystal edges are clearly visible. Most of the grains are buried in thin films and exhibit typical octahedral features.

2.2. Raman analysis of diamond films

![Figure 2](image2.png)

**Figure 2.** Raman spectra of different carbon source concentrations.
Raman spectroscopy was used to detect and analyze the diamond film. The quality of the diamond crystal and the purity of diamond can be obtained from the intensity of the Raman peak. In the Raman spectrum, the Raman characteristic peak of diamond is at 1332.5 cm\(^{-1}\). The scattering peak of the crystalline graphite structure component generally appears at 1580 cm\(^{-1}\), and the scattering of amorphous carbon component occurs. The peak is located at 1350-1600 cm\(^{-1}\). The specific location is determined by the relative content of non-diamond impurities in the diamond film. The Raman spectra of diamond films are shown in the figure 2. Raman spectra of diamond films with 1% carbon source concentration have obvious diamond Raman features at 1339 cm\(^{-1}\), indicating that the lattice of the film is mainly with the combination of sp\(^3\) key, the Raman characteristic peak of the diamond film with 1% carbon source shifts to high wave number relative to the characteristic peak of natural diamond 1332.5 cm\(^{-1}\), indicating that there is residual compressive stress inside the film.

2.3. XRD phase analysis

![Figure 3. XRD pattern of diamond film.](image)

The lattice constant of hot filament chemical vapour deposited diamond film is close to that of natural diamond, indicating that the film is a high quality diamond, but, due to the presence of stress in the film, lattice distortion is caused, resulting in a certain amount of deviation of the lattice constant. Shift. Figure 3 shows the diamond film XRD pattern. It can be seen from the figure that the <111> and <220> crystal planes of the diamond correspond to the diffraction peaks with 2θ of 43.9° and 75.2°, respectively. When the methane concentration is 1%, the intensity of the <111> and <220> crystal plane diffraction peaks is significant. The other obvious WC peaks in the figure are the characteristic peaks of the carbide cutting tool substrate. This is mainly due to the fact that the thin diamond film is easily penetrated by X-rays.

By analysing the half-width of the diffraction peak of the <111> plane of the film, it can be found that the <111> surface diffraction peak of the 1% methane concentration film has the smallest FWHM, the diamond crystallinity is high, and the <111> surface of the 1% methane concentration film. The ratio of the characteristic peak to other characteristic peak intensities is much higher than that in natural diamond, indicating that a 1% methane concentration film is a <111> oriented diamond film.

2.4. Bonding strength of membrane

![Figure 4. Surface scanning electron microscopy diagram of diamond-coated tools.](image)
Using a diamond-coated cutter, conducting a milling test study and cutting a white marble stone (CaCO$_3$, MgCO$_3$, SiO$_2$). Figure 4 shows the wear of diamond-coated ball end mills' cutting edges for one hour in the milling process. Due to the continuous impact and friction of the white marble stone on the tool flank, the diamond-coated tools all exhibit typical flank wear. Grain wear? Figure 5a shows a 1% carbon source diamond coated tool. The flank wear of the tool is normal wear with no obvious peeling of the coating. The diamond coating reduces impact and friction during cutting. Figure 5b shows an uncoated tool. The flank wear of the tool is severe and the cemented carbide substrate is significantly damaged.

From Raman analysis under 1% methane concentration, the purity of diamond under 1% methane concentration is very high, and only a small amount is sp$^2$ bond carbon. Therefore, the binding force at the interface is the strongest, and there is no obvious shedding phenomenon after one hour of cutting.

3. Conclusions
By preparing a diamond-coated tool and performing a milling test, the following conclusions can be drawn:

1) 1% carbon source concentration diamond coating, diamond grain size, sp2 bond less, $<111>$ crystal surface characteristic peak intensity, grain orientation is microcrystalline diamond, the film base binding force is high.

2) Diamond-coated cutters, after wear, analysis of flank wear shows that: from the perspective of diamond coating wear after cutting, the coating of 1% carbon source concentration diamond-coated cutter is combined with the matrix. When high, the wear of the back face of the milling cutter is small, there is no obvious peeling of the diamond coating, and the diamond coating has a certain effect of reducing impact and friction. The flank wear of the uncoated tool is severe and the matrix is significantly damaged.

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