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A super-high speed polishing technique for CVD diamond films

S.T. Huang, L. Zhou *, L.F. Xu, K.R. Jiao

School of Mechanical Engineering, Shenyang Ligong University, Shenyang 110159, China

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ABSTRACT

A new set-up for polishing of CVD diamond films on a high speed rotating titanium plate has been developed. The influence of polishing pressure on the surface character, roughness and material removal rate have been studied by using scanning electron microscopy, stylus profilometer, X-ray photoelectron spectroscopy and Raman spectroscopy before and after polishing, respectively. The results showed that the material removal mechanism is mainly the chemical reaction between carbon and titanium and the diffusion of carbon atoms into the polishing plate during the super-high speed polishing. The current method exhibits a high polishing rate in only a few hours. This preliminary result reveals a great potential for commercializing.

1. Introduction

Chemical vapour deposition (CVD) diamond films are very promising material for numerous mechanic, thermal management, optical, electrical and electronic applications. The columnar growth nature of CVD diamond films results in a very rough growth surface and surface roughness steeply increases with film thickness, and excessive surface roughness places limitations on where they can be used. Polishing can improve the optical transmission of diamond by reducing the scattering of incident light, reduce the thermal resistance in thermal management, lower the friction coefficient for mechanical uses, improve the performance of electronic devices, etc [1]. Thus, surface polishing is critical for most application. However, polishing of diamond films is a very difficult task since it is the hardest and most chemically inert material in nature.

Although numerous polishing methods have been explored for years, including mechanical polishing [2–4], thermal–chemical polishing [5–7], electrical discharge [8], laser and ion beam polishing [9–11], or a synergistic combination of these methods [12,13]. Dynamic friction polishing is a newly proposed method in recent years, and appears as an attractive alternative to supplement the deficiency of those conventional polishing methods since the equipment required for this technique is simple and the polishing process can be implemented at normal atmospheric pressure. During dynamic friction polishing process, the peripheral speed of the metal polishing plate is not more than 25 m/s and most of the polishing plates are made of steel [14,15], which is due to the iron not only possesses the highest diffusion coefficient for carbon, but also has a high solubility of carbon atoms at the eutectic temperature.

It is well known that titanium and its alloy have many attractive properties, for example high specific strength, lower thermal conductivity coefficient and the greatest diffusion coefficient of carbon atom in titanium among refractory metals [16]. At the same time, the lower thermal conductivity coefficient of titanium metal results in a higher value of temperature rise at the interface due to the friction between the diamond film and polishing plate. Therefore, in the paper, the pure titanium was selected as a polishing plate and its peripheral speed was 60 m/s. The mechanism of super-high speed polishing is similar to that of dynamic friction polishing. The super-high speed polishing technique utilizes the thermochemical reaction between a diamond film surface and a metal plate, and the heat generated at the contact interface due to the friction between the polishing plate and the diamond film while the polishing plate rotating at super-high speed.

In the present work, pure titanium was chosen as the polishing plate, the effects of polishing pressure on surface character, roughness, material removal rate were also investigated.

2. Experimental details

2.1. Materials

The initial CVD diamond films were deposited by the hot filament method and the thickness is 1 mm. The samples for polishing were cut as squares with dimension of $10\times10\ mm^2$. Scanning Electron Microscope (SEM) and profilometer were used to investigate the surface morphology and roughness of the CVD diamond films,

* Corresponding author. Tel./fax: +86 24 24682119.
E-mail address: lizhou@imr.ac.cn (L. Zhou).

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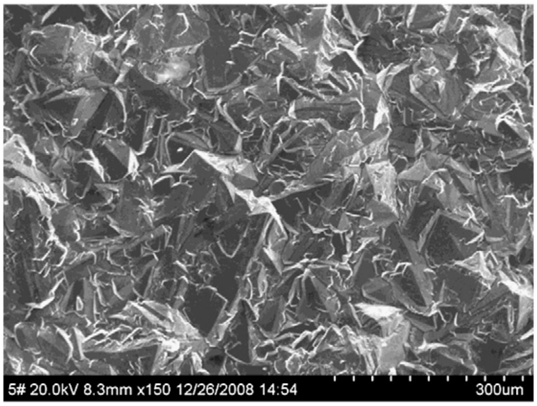

Fig. 1. SEM image of the surface morphology of the CVD diamond film.

respectively. As shown in Fig. 1, the average surface roughness (Ra) is about 16.67 μm and the size of the grains constituting the films varied from 40 to100 μm.

2.2. Apparatus and procedures

The experiments were carried out on a designed polishing machine with the schematic structure shown in Fig. 2. The sample of diamond film could be fixed in a holder and pressed against the pure titanium polishing plate with a weight. Because the thickness of the titanium polishing plate is only 5 mm, in order to increase the rigidity and make it easy to adjust the surface flatness, the polishing plate was combined with pure titanium and Al alloy, and the maximum diameter and thickness of the composite polishing plate were 300 and 15 mm, respectively. The plate was driven to rotate at a speed of 6000 revolutions per minute (rpm) by a motor and the sample holder reciprocated in the radial direction. The load added on the holder can help to adjust the polishing pressure. Four pressures (0.1, 0.17, 0.24 and 0.31 MPa) are tested in this experiment. Although a higher polishing pressure would increase the material removal rate [17], which is believed due to the larger pressure could result in a higher temperature rise and a faster chemical reaction of diamond will occur, and it may also result in more and deeper micro cracks. Therefore, too large pressure may cause in fracture of CVD diamond films during the polishing period.

Prior to the polishing process, the CVD diamond films were cleaned by alcohol and dried. The stylus profilometer and SEM were used to measure surface roughness and characterize morphology of the samples, respectively. Surface chemical state information both of the diamond film and polishing plate were obtained with an ESCALAB250 X-ray photoelectron spectroscopy (XPS). The surface quality of CVD diamond films were investigated by Raman spectroscopy before and after polishing. In order to investigate the material removal rate, the thicknesses of the polished diamond films were also tested by using SEM.

3. Results and discussion

3.1. Surface morphology

3.1.1. Untreated surface morphology

Fig. 3 shows the typical SEM images of polished CVD diamond film under four different pressures after 9 h of polishing at a speed of 6000 rpm. The surface morphology is changed dramatically with increasing the polishing pressure. The original pyramidal-like structure on the surface was smoothed, and a thin layer of metal/carbide was adhered to the surface of polished CVD diamond films. From Fig. 3a, it can be seen that only a part of diamond film surface has been adhered, and the protuberant crystal grains were entirely removed, which results in a relative smooth surface. From the energy dispersive X-ray (EDX) analysis presented in Fig. 4, the adhesion layer on the surface of polished CVD diamond films mainly consists of Ti (see Fig. 4b), and the smooth surface mainly consists of C (see Fig. 4c). With the increasing of pressure, the adhesion phenomenon became more and more serious. Comparing Fig. 3b and c, it can be observed that both the adhesion area and thickness of adhered layer increase with increasing pressure. When the pressure increased to 0.31 MPa, the surface of diamond film was more rough and uneven. Therefore, it can be concluded that when the polishing pressure increases, the friction force and temperature on the surface of diamond film will increase, and the energy for driving carbon atoms diffusion and reaction increases. At the same time, it can be observed that there are many broken diamond debris in the uneven surface (see Fig. 3d), which will be discussed later.

3.1.2. Surface morphology after treatment

All the samples after polishing were chemically cleaned in a solution of concentrated HCl and HNO_3, then a mechanical polishing (with SiC paper) and ultrasonic baths of ethanol. Fig. 5 shows the surface morphology of the diamond films after removing the adhered layer. When the polishing pressure is low (as illustrated in Fig. 5a and b), the diamond pyramid has been flattened and only some deeper etch pits around the crystal boundaries could be observed. These pits can be seen clearly from the high magnification SEM images of polished diamond films, as shown in Fig. 6a and b. Typically, the size and density of the deep pits are a function of crystal density and size, which is due to the growing of crystals at different angles. From Fig. 5a and b and their enlarged Fig. 6a, b, it can be also observed that the surface morphology of most regions looks very flat and smooth, almost all the pyramidal diamond crystals were polished to a plane surface, and there was no scratch on the plane of diamond crystals. With the pressure increasing, the deep pits around the crystals become less evident and the micro-cavities increase markedly (see in Fig. 5c and d), which can be observed clearly in the enlarged part of Fig. 6c (see Fig. 7). It is well known that the diamond is very brittle, with the rising of polishing pressure, the friction force and the shear stress on the surface of diamond film increase. As a result, there are more cracks generating at the contact areas of diamond peaks, which can also be observed clearly in Fig. 7. In comparison with samples (a)–(d) in Fig. 5, higher pressure seems to take a disadvantage of better surface smoothness. It's reasonable because higher pressure could result in more and

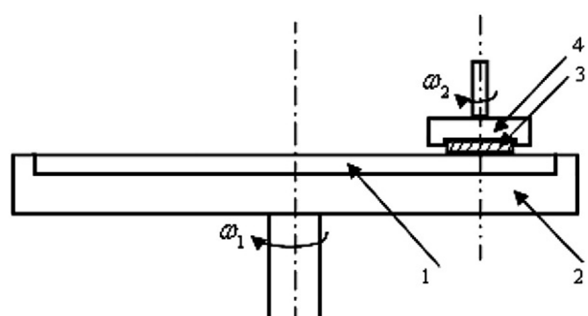

Fig. 2. Schematic illustration of diamond film polishing set-up.1: pure titanium polising plate, 2: Al alloy supporting plate, 3: diamond film, 4: CVD specimen holder.