Effects of Surface Modification on Improvement of Diamond Coating on Tungsten Carbide Cutting Tool

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Abstract—**In our present work, surface modification techniques including Co removal and micro blasting were developed for CVD diamond film coating process on tungsten carbide router bit. Microwave plasma jet chemical vapor deposition system was employed to deposit diamond films onto the as-prepared WC router. Scanning Electron Microscopy (SEM) and Optical Microscopy (OM) were used to investigate the surface morphology of the samples. Raman spectroscopy and energy-dispersive X-ray spectroscopy (EDS) were used to analyzed the microstructure and fraction of the films. The result showed that the developed surface modification processes could significant improve the cutting performance and tool life as 220%. The above results indeed demonstrate a potential applications of diamond coating for cemented carbide tools.**

Index Terms—**diamond, tungsten carbide, chemical vapor deposition, cutting tool**

I. Introduction

Diamond films have attained much attention over decades for many engineering fields due to their outstanding characteristics include extreme hardness, chemical inertness, wear resistance, optical transmittance, and biocompatibility [1]-[5]. Chemical Vapor Deposition (CVD) diamond coating have been developed for various applications such as optical-semiconductor sensor, biochemical sensor, heat sink, and anti-wear resistant [6]-[10]. Especially, thanks to their good physical properties, CVD diamond films are most promising candidate for machining tool [11]-[15].

Tungsten carbide (WC) are one of excellent powder metallurgy materials for their uses in mechanical parts, manufacturing, and metal cutting tool process. The uses of WC cutting tool, however, have been hindered by few problems such as built-up edge, plastic deformation of the tool, and poor wear resistant of both flank and crater, resulting in short tool life as well as accuracy of machining process. Therefore, much efforts have been devoted to overcome the aforementioned challenges, leading to intensively investigations in high performance engineering materials as protective coating. Recently, diamond coatings have been studied for improvement in cutting performance as well as lifetime of WC cutting tools. The fate of those diamond protective coating depends on adhesion with WC substrate and manufacturing cost. Nevertheless, Co fraction as binder in W-C-Co power metallurgy system is reported to promote graphitization during CVD process, resulting in formation of non-diamond phase layer on surface of WC substrate, and thus lead to poor adhesion of the diamond coating. Many studies have been devoted for Co removal as surface pretreatment for the diamond deposition on WC cutting tool, however, this process is also considered to obstruct intrinsic mechanical properties of WC and thus optimization in process parameters indeed become all of importance. In this paper, we present a complete surface modification method for diamond film deposition on WC cutting tool aiming at good adhesion.

II. Experimental Details

In this study, WC-Co 6 w.t% router bits were used for all experiments. The samples were first rinsed with methanol and acetone (Sigma Aldrich) for each 10 min then dried by nitrogen flow at room temperature. Prior to deposition, a chemical etching process were performed aiming at removal of Co fraction from the substrate surface. The WC-Co router bit was firstly ultrasonically etched in the mixture of 10 ml 98% H_2SO_4 + 30 ml 38% H_2O_2 for 10–30s. In order to improve etching performance, the acid etching process was also conducted at temperature of 120^{o}C. The Co removal is considered to produce a light pink color of the liquid which is feature of cobalt salts, therefore all the samples were thoroughly rinsed by double-distilled water with ultrasonication enhancement five times as a transparence liquid was obtained. Finally, in order to enhance diamond nucleation density for CVD process, the router bits were nucleated by ultrasonication method with solution of ultradispersive detonation diamond nanoparticles having grain size of 8-10 nm.

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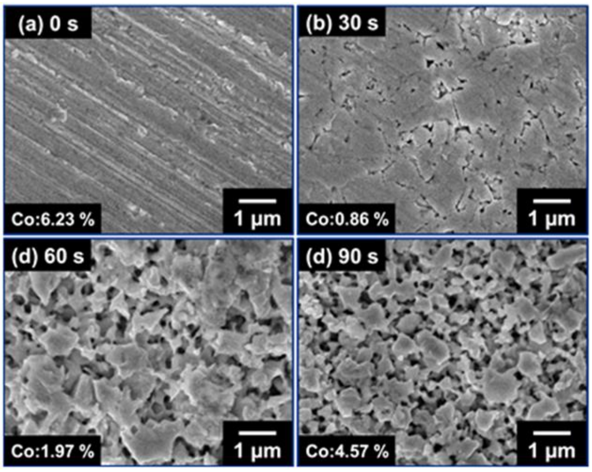

Figure 1. SEM images of (a) original and the as-treated WC router bits after etching procedures for (b) 30s, (c) 60s, and (d) 90s.

The diamond films were deposited onto the as-treated router bits in a home-made microwave plasma enhanced vapor deposition (MPECVD) system. The plasma was induced by microwave power of 1000 W using gas mixture of 2% CH_4: 98% H_2 as precursor gases. The working pressure and deposition time were fixed at 45 torr and 2 h of all experiments, respectively. During deposition process, optical emission spectrometry was employed to monitor the generated carbon species. Field emission scanning electron microscope and energy-dispersive X-ray spectroscopy were used to investigate the effects of etching process on surface morphology and microstructure of the samples. X-ray diffraction was also used to analyze the crystallinity of the as-deposited diamond films.

III. Results and Disscussion

The surface morphology of original and as-pretreated WC-Co router bits were investigated by SEM and EDS techniques. Showing on Fig. 1(a), Co fraction of the pristine substrate were calculated as 6.23 %, which is characteristics of WC-Co cutting tools produced by powder metallurgy process. After 30 s of the etching procedure (Fig. 1(c)), surface morphology of the router bits showed a significant change with formation of island shapes and holes. Fig. 1(d) shows porous morphology of the router bits after 90 s of acid treatment process, as result of the disappearance of Co binder. It should be noted here that the too low Co fraction can hinder the intrinsic characteristics of WC materials. From Fig. 1(b)-(d), Co fraction were seen to increase with the increasing of reaction time. This can be explained by consideration in deep etching as result of long duration process. The increase in Co fraction on surface of WC router bits is well-known to lead to graphitization during diamond growth.

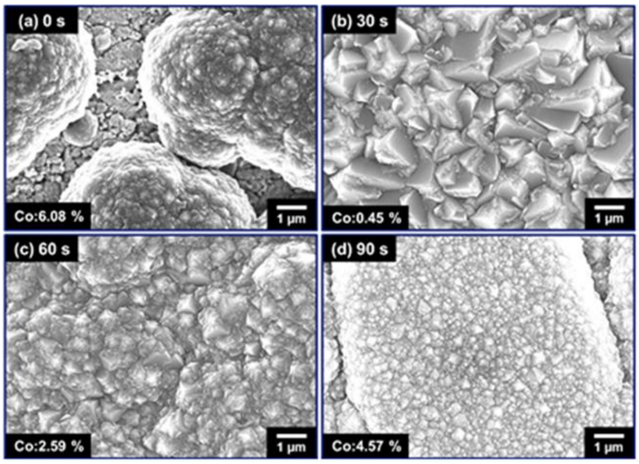

Figure 2. SEM images of the as-deposited diamond films on (a) original and the as-treated WC router bits after etching procedures for (b) 30s, (c) 60s, and (d) 90s.

Fig. 2 shows the surface morphologies of the diamond films deposited on WC router bits treated for etching time. For the original substrate, SEM image shows a discontinuous morphology of the film with discrete grains (as shown in Fig. 2(a)). The diamond film deposited on router bits treated for 30 s shows a continuous and uniform microcrystalline diamond film having diamond grain size of 1 μm. The well facet diamond grain is induced by hydrogen-etching of the generated non-diamond carbon phase under high H_2 concentration plasma and leads to the formation of large grain size. The formation of microcrystalline diamond film demonstrate the advantages of the etching procedure which contributed in removal of Co fraction existed on the surface of WC router bits, and thus hindering the generation of graphite phase during CVD process. Fig. 2(c)-(d) shows the SEM images of diamond films deposited on the WC router bits after longer etching time of 60 s and 90 s, respectively. After 60 s of etching time, the diamond crystallite size changed to sub-micron with cluster on the surface. Increasing in etching time can lead to smaller size of diamond grain as revealed in Fig. 2(d) which is resulted by higher Co fraction on the surface of the WC router bits. Further investigation in microstructure of diamond films were carried out in ultraviolet Raman spectroscopy (λ = 325 nm). The spectra of diamond films deposited on pristine WC router bits shows the typical peaks of nanocrystalline diamond films. The diamond peak at 1332 cm^{-1} as characteristics peak of sp^3 hybridized carbon is relatively weak while the clearance of G-band at 1580 cm^{-1} reveals a large proportion of sp^2 phased carbon from grain boundaries [16]-[21]. The peaks at 1140 cm^{-1} is attributed to C-H bonds. The films deposited on the WC router bits etched for 30 s show a spectra of micrystalline diamond with sharp peak of diamond phased carbon, and also the disappear of G-band. The above analysis in Raman spectra is well agree with the aforementioned SEM data.

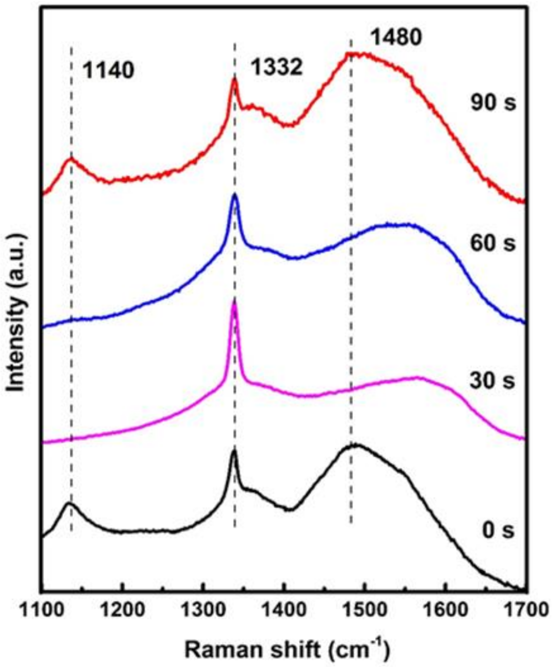

Figure 3. Raman spectroscopy of the as-deposited diamond films on original and the as-treated WC router bits after etching procedures for 30 s to 90 s, respectively

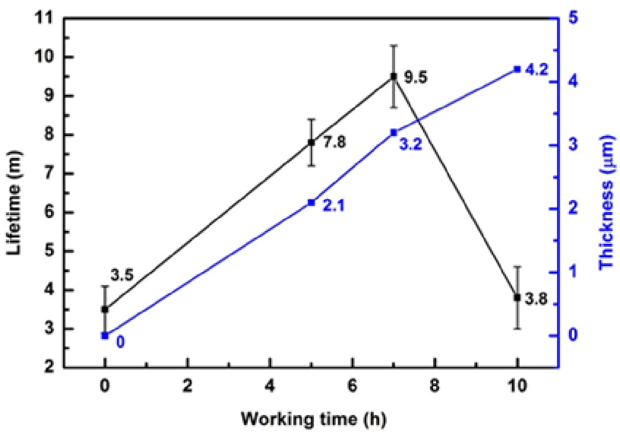

Figure 4. Tool life measurements of WC router bits coated diamond films with various thickness

Fig. 4 plots the tool lifetime as a function of thickness of diamond coating on WC router bits. In our experiments, the CH_4:H_2 flow rate ratio were fixed at 2:98 to ensure the deposition of microcrystalline diamond films. In order to investigate the effect of thickness of diamond coating and the tool lifetime, a practical measurement were designed and employed for the machining of aluminum foil-based printed circuit board. In all experiments, the angular and feed rate of the cutting tool were fixed at 35000 rpm and 120 mm/min. The lifetime of un-coated WC router bit was 3.5 m. After coating with 2.1 μm of diamond film, the tool lifetime was significant improved by 110% (with 7.8 m of tool life). The increase in diamond coating thickness can be seen to increase the performance of WC router bit. The measured tool life of cutting tool coated with 9.5 μm of diamond film. However, the tool life was clearly decreased to 3.8 m since the thick film may produce large internal stress and thus result in peeling of the diamond coating. This lead to the need of further development in deposition process.

IV. Conclusion

In this paper, a surface modification was developed to deposit diamond film onto WC-Co router bits by microwave plasma enhance chemical vapor deposition techniques. It is found that the etching procedures have significant effects on the diamond growth on the router bits. The Raman spectra revealed that high quality microcrystalline diamond film was successfully obtained by 30 s of etching time. Also, long duration of the pretreatment induces porous structure of the router bits and island-shape of diamond films. The tool life was increased by 220% with 9.5 μm of diamond coating thickness. The above results indeed demonstrate an avenue of the use of surface modification in diamond deposition on WC cutting tool as well as the applications of this coating on engineering fields.

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