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Machining Characteristics of SiC reinforced Composite by multiple diamond-coated drills

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다이아몬드 피복공구에 의한 SiC 강화 복합재료의 절삭특성

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ABSTRACT

Compared to sintered polycrystalline diamond (PCD), the deposited thin film diamond has a great advantage on the fabrication of cutting tools with complex geometries such as drills. Because of high performance in high speed machining non-ferrous difficult-to-cut materials in the field of automobiles industry, aeronautics and astronautics industry, diamond-coated drills find large potentialities in commercial applications. However, the poor adhesion of the diamond film on the substrate and high surface roughness of the drill flute adversely affect the tool life and machining quality and they become the main technical barriers for the successful development and commercialization of diamond-coated drills. In this paper, diamond thin films were deposited on the commercial WC-Co based drills by the electron aided hot filament chemical vapor deposition (EACVD). A new multiple coating technology based on changing gas pressure in different process stages was developed. The large triangular faceted diamond grains may have great contribution to the adhesive strength between the film and the substrate, and the overlapping ball like blocks consisted of nanometer sized diamond crystals may contribute much to the very low roughness of diamond film. Adhesive strength and quality of diamond film were evaluated by scanning electron microscope (SEM), atomic force microscope (AFM), Raman spectrum and drilling experiments. The ring-block tribological experiments were also conducted and the results revealed that the friction coefficient increased with the surface roughness of the diamond film. From a practical viewpoint, the cutting performances of diamond-coated drills were studied by drilling the SiC particles reinforced aluminum-matrix composite. The good adhesive strength and low surface roughness of flute were proved to be beneficial to the good chip evacuation and the decrease of thrust and consequently led to a prolonged tool life and an improved machining quality. The wear mechanism of diamond-coated drills is the abrasive mechanical attrition.

Key Words : Diamond-Coated Drill, High Speed Machining, Composite

1. Introduction

Diamond has been regarded as the perfect cutting-tool material for its inherent properties such as extreme hardness, high thermal-conductivity, low thermal-expansion coefficient and high corrosion resistance. Diamond cutting tools are suitable for high speed machining non-ferrous difficult-to-cut materials such as high silicon aluminum alloys, SiC particles reinforced aluminum-matrix composites, titanium alloys, and engineering ceramics. Compared to the sintered polycrystalline diamond (PCD), the deposited thin film diamond has a great advantage on the fabrication of cutting tools with complex geometries such as drills, reamers, solid end milling cutters, and taps [1,2]. The electron aided hot filament chemical vapor deposition (EACVD) is a popular technology to fabricate the diamond cutting tools. Peeling of diamond film usually occurs due to lack of adhesive strength and yields very short tool life. If the surface roughness of diamond film is high, it will deteriorate the chip evacuation capability of the flutes and lead to overload of cutting tool, adversely affecting the tool life and machining precision and quality. Up to now, the poor adhesion of the diamond film on the substrate and high surface roughness are the main technical barriers for the successful development and commercialization of diamond-coated drills.

WC-Co cemented carbide is the very common substrate for cutting tools. Unfortunately the Co plays as a catalyst for graphite formation during the EACVD process and will be destructive to the adhesion of the diamond coating on the substrate. Removal of the Co from the surface is very important for the improvement of adhesive strength. The particular pretreatment of removing Co has been studied successfully for the cemented WC-Co substrate with complex geometries [3].

The surface roughness of diamond film has a close relationship with the friction coefficient of tool-to-workpiece, which affects the chip evacuation, cutting forces and consequently tool life and machining quality. This paper investigated the tribological property of the diamond film by ring-block wearing experiments. In the EACVD process, adhesive strength of diamond film and its surface roughness depend much on the process parameters. The new multiple coating technologies based on changing the gas pressure are discussed. From a practical-application viewpoint, cutting performances of the diamond-coated drills were studied by drilling the SiC particles reinforced aluminum-matrix composites with the consideration of cutting tool wear mechanism and chip evacuation.

2. Experimental Conditions

The EACVD system with special fixture was used to fabricate diamond-coated drills. The cemented tungsten carbide K10 drills were used as the substrates. Tantalum wires were used as hot filaments and the drills were placed among wires with H_2 and acetone as reaction sources. The conventional gas pressure was 30~40 torr. The acetone concentration was 1-3vol%. The filament temperature during the deposition was 2200 ℃. The substrate temperature was 700~850℃. The bias current density was 0.1~0.3A/cm^2. The distance between the substrate and filament was 5mm. The deposition time was 4-5h. The thickness of coating was 10-15μm. The scanning electron microscope (SEM) and atomic force microscope (AFM) observations were conducted to inspect the surface morphologies of the diamond film and the wearing characteristics. The chemical constitutes of the diamond films were evaluated by Raman spectrum. The tribology studies were conducted on MM-200 ring-block wearing tester. The rings were made of SiC particles reinforced aluminum-matrix composites and the blocks were diamond-coated samples with different surface roughness. The load to blocks was 20kg, and the total sliding distance was 3016m. The rotation rate was 400rpm. In order to accelerate wearing process during drilling , the solid plates of 15vol% SiC particles reinforced aluminum-matrix composites were used as the workpieces. The DMU70V machining center was used to perform the drilling tests. The maximum spindle speed was 12000rpm. The signals of torque and thrust were picked up by a Kistler dynamometer measuring system. After each drilling iteration, the abrasion width of outer cutting edge corner of the drill was examined by a tool microscope. The BJ-3C surface tester was used to measure surface roughness of the workpieces and the surface scanning profilometer (ALPHA-STEP500) was used to measure the surface roughness of diamond films with 600μm scanning length and 50μm/s scanning velocity.

3. Results and Discussions

3.1 Tribological Tests and Multiple Coating Technology.

The surface roughness of diamond film has a close relationship with the friction coefficient of tool-to-workpiece, which affects the chip evacuation and cutting forces, and finally cutting tool life. In fact, reduced surface roughness of cutting tool lowers the friction force and prolongs tool life and improves machining quality. The tribological properties of diamond films with different roughness were studied through a series of ring-block wearing experimental tests. As demonstrated in Fig.1, it is clear that the friction coefficient increases with the surface roughness of the diamond film.

The surface roughness of diamond film relies much on the EACVD parameters. The increase of carbon source concentration and the decrease of substrate temperature as well as the gas pressure lower the surface roughness of diamond film. But on the other hand, the adhesive strength between the film and the substrate may get simultaneously deteriorated. The large triangular faceted diamond grains may enhance the adhesive strength between the film and the substrate, but unfortunately result in a rougher surface with a high friction coefficient. On the contrary, the small square faceted or spherical diamond grains may give a smoother surface with lower friction coefficient, but unfortunately they result in the poor adhesive strength between the film and the substrate. In this study, a new

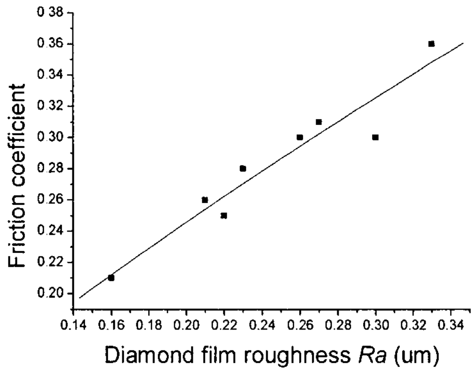
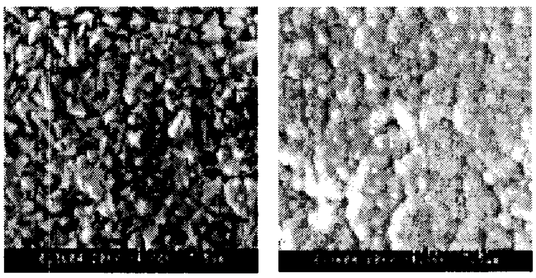


Fig.1 The relationship between the friction coefficient and diamond film roughness.

multiple coating technology was adopted to obtain high quality diamond film on the drill substrate with smooth surface roughness and high adhesive strength as follows. At the initial stage of EACVD process, large triangular faceted diamond grains were obtained on the substrate forming rough diamond film under the conventional gas pressure of 40 torr with 1% concentration of carbon source. At the later stage of EACVD process, the small ball like



(A) (B)

Fig.2 The surface morphology of the diamond film. (A) Conventional coating; (B) Multiple coating.

blocks were obtained when the gas pressure was decreased to 10 torr with 1% concentration of carbon source. The small ball like blocks overlapping on the previous rough diamond film exhibited a smooth diamond film. Figure 2A and 2B show the surface morphology of the diamond film deposited by the conventional coating technology (just keeping gas pressure of 40 torr with 1% concentration of carbon source) and the multiple coating technology respectively.

The atomic force microscope (AFM) inspection

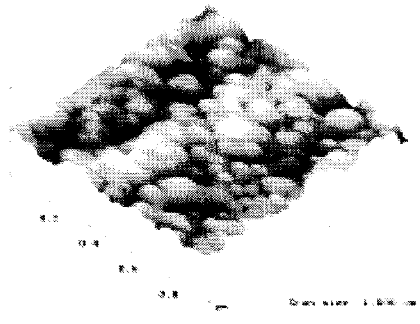


Fig.3 The nanometer grains morphology measured by atomic force microscope.

showed that the overlapping ball like blocks consisted of nanometer sized diamond crystals, as seen in Fig.3. These crystals contributed much to the very low roughness of diamond film. The chemical constitutes of the diamond films were evaluated by Raman spectrum as seen in Fig.4. Both the curves showed the sharp peaks of diamond at 1333 cm^{-1} with the weak broad peaks of non-diamond carbon near 1550 cm^{-1}. The results indicated that the diamond film obtained by conventional coating technology or multiple coating technology was mainly

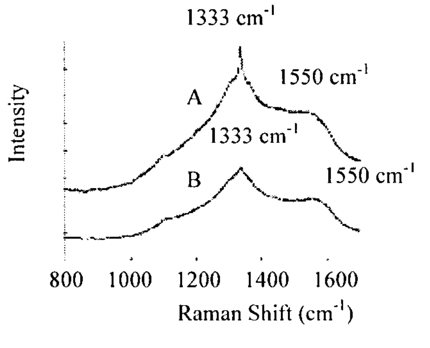


Fig.4 The Raman spectrum of diamond film. A-Conventional coating; B-Multiple coating.

composed of highly crystallized diamond with very low non-diamond carbon. Such a film yields a high adhesive strength.

3.2 The Drilling Tests

Series of drilling tests were conducted with three kinds of drills of 4mm in diameter. Spindle speed was 7000r/min. Feed rate was 0.1 ~ 0.2mm/r. Hole depth was 5mm. Figure 5 shows the values of the measured abrasion width of outer cutting edge corner with the number of holes. In drilling the initial 5 holes, all three drills exhibited the acute initial attrition. After the 5th hole, the uncoated drill continued to experience acute wear and it finally broke

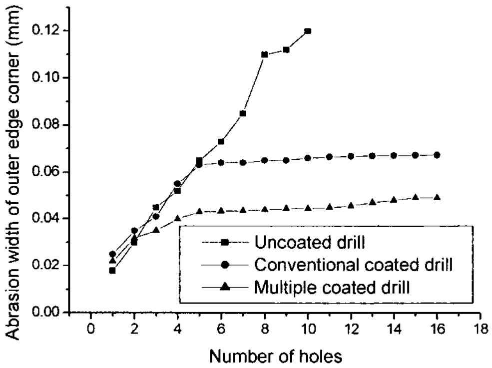


Fig.5 Abrasion width of outer cutting edge corner with the number of holes.

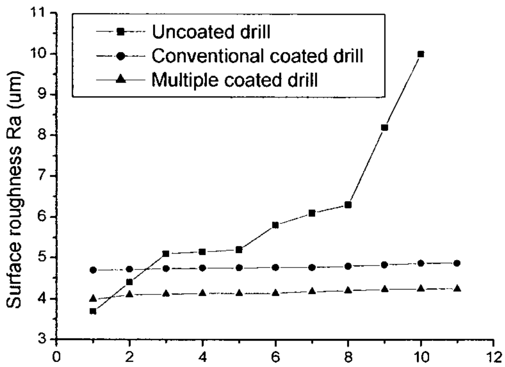


Fig.6 Surface roughness of workpiece with the number of holes.

into pieces during drilling the 10th hole. The two kinds of diamond-coated drills seemed to withstand the abrasive wear after the acute initial attrition of first 5 holes and kept the abrasion width of outer cutting edge corner to be constant. With the drilling process, the conventional coated drill could work till the 27th hole and the multiple coated drill could work till the 45th hole.

Figure 6 shows the curves of surface roughness with the number of holes and Fig.7 shows the signals of cutting torque and thrust during drilling the 10th hole with the different drills. The uncoated drill exhibits the biggest thrust as seen in Fig.7A. As seen in Fig.7C, the multiple coated drill exhibits the smallest thrust due to good chip evacuation along the smooth flute. It is clear that the diamond-coated drill yields better cutting performance than that of the uncoated drill. Because of high adhesive strength and low surface roughness of diamond films, the multiple coated drill yields longer tool life and smoother holes than those of the conventional coated drills.

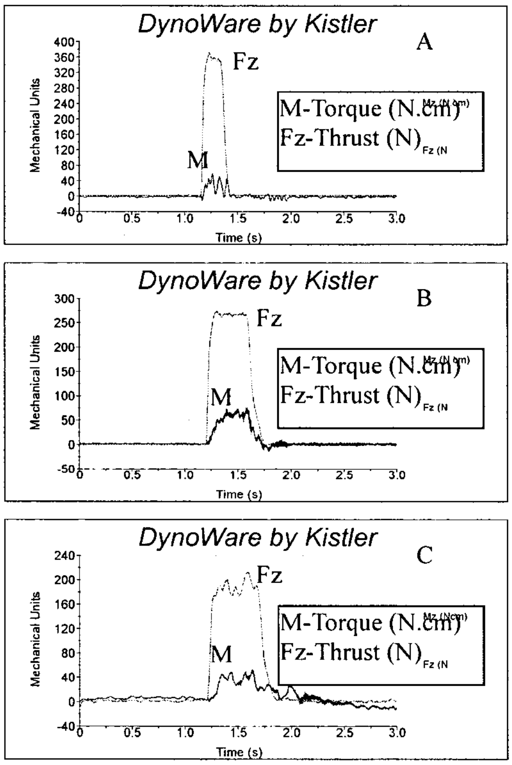
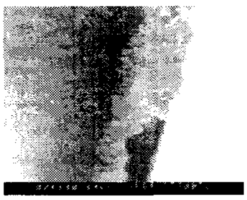


Fig.7 Torque and thrust signals in drilling the 10th hole. (A)Uncoated drill; (B)Conventional coated drill; (C) Multiple coated drill.

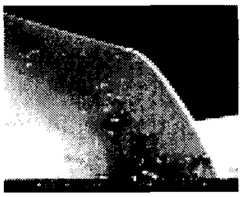
Figure 8 shows the abrasion morphology of cutting edges of the different drills. The uncoated drill experienced the excessive mechanical plowing and attrition by the abrasive SiC particles in the workpiece, and furthermore, the built-up-edge was easily formed due to severe friction between aluminum-matrix composite and drill flute, as seen in Fig.8A. The diamond-coated drills experienced three wearing stages, i.e. initial acute attrition, long stable wearing period, and rapid final failure.

The initial load impact to the workpiece was the main reason for initial acute attrition due to the loss of diamond grains at the local cutting edge, especially at the corner point, as seen in Fig.8B. But after the initial attrition stage, the remained diamond grains exhibited excellent wear resistance and therefore yielded long tool life and stable

(A)



(B)



(C)

Fig.8 The abrasion morphology of the cutting edges. (A)Uncoated drill; (B)Conventional coated drill; (C) Multiple coated drill.

drilling process. The tool life was finally determined by the large peeling of diamond film and serious deterioration of workpiece surface quality. The multiple coated drill had smooth flute surface which was beneficial to chip evacuation capability and resulted in small cutting thrust. The sharp and uniform cutting edge can be found in Fig.8C. The wear mechanism of diamond-coated drills in drilling SiC particles reinforced aluminum-matrix composites is the abrasive mechanical attrition.

4. Conclusions

The drills fabricated by multiple coating technology are of high adhesive strength as well as low surface roughness of diamond films. These drills therefore yield longer tool life and smoother holes than those of the conventional coated drills. The smooth flute surface of multiple coated drill is beneficial to chip evacuation and results in small cutting thrust. The wear mechanism of diamond-coated drills in drilling SiC particles reinforced aluminum-matrix composites is the abrasive mechanical attrition.

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