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COATED DIAMONDS AND DIAMOND COATINGS (A REVIEW OF CURRENT DEVELOPMENTS)

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Abstract. *Recent studies have shown the effectiveness of coating diamond grains with thin layers of titanium and nickel to provide a tight interface with the nickel matrix. Wetting of diamond and nickel is improved by coating diamond particles with thin layers of titanium and nickel. Titanium carbide formed between Ti-coating and diamond provides stronger interfacial adhesion force compared to diamond micropowder with Ni-coating. To improve the thermal properties of diamond/metal composites, a metal carbide layer is needed that combines both the crystal structure and the heat transfer of heterogeneous interfaces. In modern research in coatings, in addition to TiC, attention is paid to other carbides:* B_4C, V_2C *and VC, as well as chromium carbides. A separate direction is oxide coatings on diamonds. The mechanism of diamond protection in this direction is the predominant oxide donor behavior of Mo–B–C coatings for the formation of a stable oxide layer on the diamond surface. Diamond films with three different grain sizes were grown on the surface of a titanium alloy by high-temperature chemical vapor deposition (HFCVD). The corrosion resistance of nanocrystalline diamond (NCD) films is clearly higher than that of microcrystalline diamond (MCD) films. But cutters with intact MCD coating demonstrate the longest service life. Attention has been paid to coatings applied to hard alloys and steels, with researchers mainly focusing on coatings containing titanium, namely TiAlN, TiN/CrN and* Al_2O_3/TiO_2.

Keywords: *coated diamonds; nickel coating; titanium coating; titanium carbide; boron carbide; vanadium carbide; oxide coating; nanocrystalline diamond films; microcrystalline diamond films.*

1. Introduction

The development of tool production necessitates the efficient processing of new, difficult-to-process materials. The search for ways to save energy dictates the need to obtain composite coatings on diamond grinding powder grains with new properties. Previous studies have established that the main factors that, for example, determine their diamond retention are the boundary chemical interaction with coating elements, for example, during high-temperature manufacturing of tools on metal bonds, as well as diffusion interaction at the coating-bond interface. In diamond tools with polymer and metal-polymer bonds, chemical interaction occurs at the metal coating–polymer interface. The rougher the coating, the greater the grain surface area and the greater the efficiency of this interaction. In addition, research into coating both diamond grains of abrasive tools and diamond grains as components of diamond cutting composites and diamond-metal composites is relevant.

2. The state of the art in the field of diamond coating research

Researchers pay increased attention to the interface between diamond and matrix. Experimental results show [1] that a W-coating layer can effectively improve the wettability of the diamond surface and reduce the wetting angle from 108.6° to 13.2°. The W layer can also significantly prevent the graphitization of the diamond surface and improve the contact between diamond and copper matrix. Thus, the thermal conductivity of the W-coated composite with a diamond content of 18.4 vol.% increases and reaches 575 W/(m•K), which is 43.3% higher than that of pure Cu.

The introduction of an intermediate layer is an effective method to improve the interfacial thermal conductivity (G) of the Cu/diamond interface. In the paper [2], an amorphous carbon (a-C) layer was introduced at this interface by Ar ion bombardment, enriched with oxygen by Ar/O_2 ion bombardment, and the C-O bond was formed by acid treatment at the Cu/diamond interface. Compared to the pre-cleaned Cu/diamond interface, a 35% increase in G is achieved by obtaining a 4.5 nm thick a-C interlayer between Cu and diamond.

The low interfacial strength between the iron-based matrix and diamonds leads to premature detachment of diamond particles, which significantly affects the cutting efficiency of diamond composites. The work [3] aims to optimize the interfacial microstructure and mechanical properties of diamond/Fe-Ni-WC composites by depositing a Mo_2C layer on the diamond particles. Mo_2C-coated diamonds were prepared by the molten salt method. Diamond/Fe-Ni-WC composites were sintered by hot pressing under vacuum. Energy dispersive scanning spectroscopy showed that the Mo_2C coating layer changed the interfacial composition between the Fe–C alloy matrix and diamonds to Mo_2C, improving the interface strength. This change in interface composition results in an increase in interfacial strength, as evidenced by an increased flexural strength of 996 MPa, which is 24% higher than that of the uncoated diamond/Fe-Ni-WC composite. The increase in interfacial strength improves the holding capacity of the matrix on the diamond, which increases the height of the diamond protrusion, and the cutting efficiency of the Mo_2C-coated diamond/Fe-Ni-WC composites increases. That is, the above indicates that the application of the effect of subsequent mechanochemical influence, both on the diamond-bond interface and on the contact of the diamond grain surface with the processed material, when coating diamond abrasives, allows to increase the efficiency of using a diamond abrasive tool.

3. Formulation of the purpose of the research

The coating of diamond grains is an important factor influencing the change in their properties and increasing their retention in the binding working layer of the grinding wheel. Considering that this area is actively developing, in this work we focus on modern developments that are in scientific publications over the past 5 years. Let us point out that here we were most interested in developments in the direction of applying coatings to diamond grains, which would be used in abrasive composites and composites for cutting tools, diamond-metal composites with increased thermal conductivity, as well as the features of applying and using diamond coatings on tool materials.

4. Presenting main material

Let us first consider developments in coating diamond grains for abrasive surface treatment of various difficult-to-machine materials.

Electroplated diamond wire saws are widely used in industry. The use of nickel (Ni) coated diamonds is a common approach to improve the efficiency of the electroplating process of composites in wire saw production. However, pure diamond does not chemically react with nickel, and the interfacial bond strength between the nickel coating and diamond is relatively weak. This often leads to separation of diamonds from the nickel coating during the cutting process. To solve this problem, titanium (Ti) coated diamonds have been used in the manufacture of wire saws. Specifically, in [4], a vacuum slow evaporation technology was developed to obtain diamond micropowder (8 μm) with uniform Ti coatings, firmly bonded to the diamond through the interfacial product TiC. Linear scanning voltammetry curves showed that the addition of Ti-coated diamond shifted the overvoltage of the composite electroplating in the positive direction, therefore it promoted the electrodeposition reaction more than diamond powder. Electrochemical impedance spectroscopy showed that Ti-coated diamond reduced the charge transfer resistance during composite electroplating. The Ti-coated diamond micropowder was completely covered with a Ni electroplated layer, and the TiC formed between the Ti-coating and diamond provided a stronger interfacial adhesion force compared to that of the Ni-coated diamond micropowder (Fig. 1). The diamond ropes with titanium-coated diamond micropowder demonstrated excellent resistance to diamond grain shedding.

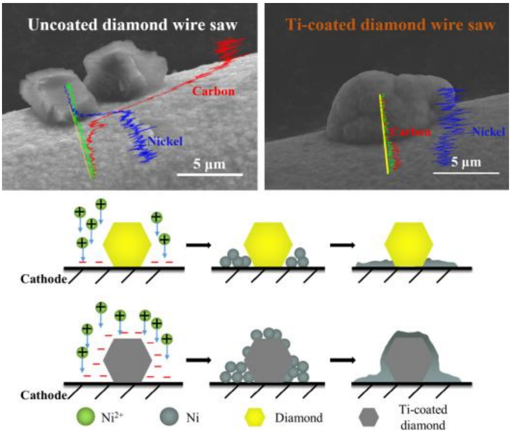

Fig. 1. Mechanism of improved retention of diamond particles with the presence of a titanium coating on them [4].

In the article [5], in order to effectively avoid thermal oxidation and thermal destruction of diamonds when working in a high-temperature aerobic environment, Mo–B–C coatings were developed and prepared to protect diamonds from oxidation. These coatings were synthesized on the diamond surface using Mo_2C-coated diamonds, boron powder, and boric acid. A two-step synthesis method was used to form coatings with different B contents on diamonds by controlling the reaction temperature, and the oxidation kinetics and oxidation mechanism of coated diamonds were investigated in the temperature range of 700–1200 °C. The mechanism of diamond protection in this study was the predominant oxidative donor behavior of Mo–B–C coatings to form a stable oxide layer on the diamond surface. For low-B coatings, four stages of coating oxidation were observed sequentially with increasing temperature, low-temperature MoO_3 evaporation, stable B_2O_3 protection, and rapid B_2O_3 evaporation. For high-B coatings, the predominant self-reducing flow of B_2O_3 not only suppressed the evaporation of MoO_3, but also provided a reducing environment for MoO_3 to form MoO_2 and Mo_2C with high melting point, which led to the formation of a double synergistic protective oxide layer and significantly improved the oxidation resistance of diamonds. Meanwhile, the oxide layer protection maintained the compressive strength of diamonds in high-temperature oxidizing atmosphere, indicating its good applicability at high temperatures. The compressive strength of individual diamond grains is an important indicator of the quality of synthetic diamonds. The average compressive strength of uncoated diamonds was 80 N. The compressive strength of coated diamonds was significantly improved to 150 and 200 N. This means that the presence of the coating compensates for the defects of synthetic diamonds by filling gaps, repairing or encapsulating, which significantly seals cracks in diamonds and reduces the stress concentration of diamond particles when they are subjected to force [5].

B_4C coatings were successfully synthesized on the surface of faceted diamond crystals by the carbothermic reduction method using a system containing B_2O_3 and B [6]. The microstructure, chemical composition, and surface morphology of the B_4C coatings were studied. The growth mechanism of B_4C was explained using a new model [6], which accurately describes its formation on diamond surfaces and agrees well with experimental data. Thus, B_4C coatings are predominantly composed of rod-shaped crystals, which show preferential deposition on the (110) diamond surface compared to the (111) surface. Furthermore, the thickness of B_4C coatings increases with increasing temperature, reaching complete and uniform coverage of both (100) and (111) diamond faces at 1200 °C. This face-dependent selectivity is due to the different atomic arrangements and energetics of the diamond surface. The (100) surface provides a more ordered structural matrix for B_4C nucleation, a process that is additionally susceptible to the lower energy of boron (B) doping defect formation ($\Delta E = 4.49$ eV) compared to the (111) surface. This thermodynamic susceptibility promotes the oriented attachment and lateral fusion of B_4C nuclei on the (100) surface, thereby accelerating the formation of the initial layer. Kinetic analysis shows that the growth of B_4C on the diamond (100) surface obeys a parabolic rate law with an activation energy of 124.7 kJ/mol in the temperature range from 1000 to 1300 °C. The growth of the B_4C coating is mainly determined by temperature and is kinetically limited by the diffusion of boron atoms, which leads to a gradual decrease in the deposition rate over a long processing time [6].

Diamond tools in the processing of ferrous metals have strong chemical wear, which makes their practical application difficult. To improve the wear resistance of diamond cutting tools in a strong covalent diamond-graphite structure obtained by laser-induced solid-state diffusion, it is possible to obtain carbon nanosheets (CNS) by electrochemically removing the graphite layer on the diamond matrix, which offers a new way to improve the limitations in the application of diamond tools [7]. After 14,400 cycles of reciprocating sliding on a GCr15 ball under a normal load of 2–8 N, the friction was reduced by 45.9–65.6% with high durability. During this process, the oxygen content is reduced by an order of magnitude, suggesting that CNS can prevent oxidative behavior at the sliding interface. The relative wear rate of bare diamond was 4.1–15.4 times higher than that of CNS. This demonstrated competitive inhibition of mechanochemical wear.

In the next stage, we will consider developments in coating diamond grains for diamond composites for various purposes.

Thus, new composite materials using silicon nitride (Si_3N_4) as a substrate and diamond particles as a reinforcing phase were developed to improve both thermal conductivity and mechanical properties [8]. Such diamond composites provided a maximum thermal conductivity of 201.96 W•m, had high hardness (32.84 GPa) and low coefficient of thermal expansion (3.07×10^{-6}/K). The titanium coating on the surface of the diamond particles promoted the formation of a titanium carbonitride (TiC_iN_{1-i}) interface between the two components during sintering, creating a strong bond for high thermal conductivity at the diamond-Si_3N_4 interface. The titanium carbonitride formed at the interface creates a chemical bond and inhibits the graphitization of diamond (about 100 nm). In addition, a multilayer material design was developed in which layers of Si_3N_4-coated diamond and Si_3N_4/Ti were stacked alternately to give the composites a directional thermal conductivity characteristic. The multilayer designs gave the composites a directional heat transfer property, and the anisotropy increased by 66.67% compared to the few-layer structure. The thermal conductivity of the fabricated Si_3N_4/diamond composites increased by 272.87% compared to the thermal conductivity of commercially available Si_3N_4, making them excellent as thermal control materials [8].

Metal matrix composites (MMCs) have received increasing attention, and recently there has been growing interest in the additive manufacturing of complex-shaped MMCs. However, quality control of the composite powder for MMCs remains a challenge. In this study, diamond particles are first coated with thin layers of titanium and nickel to ensure a tight interface with the nickel matrix. Wetting of diamond and nickel is improved by applying thin layers of titanium and nickel to diamond particles. The effect of ball milling parameters on the preparation of diamond/N6 composite powder particles with Ni-Ti coating was analyzed, as well as the effect of processing parameters during laser powder bed melting (LPBF) on the densification and defectivity of the fabricated samples. The results show that at the ball mill stage, it is possible to obtain high-flowing composite powder particles for LPBF at a ball mill time of 4 hours, a speed of 250 rpm and a ball to powder ratio of 2:1. Using the optimized composite powder, a set of diamond MMCs with Ni-Ti/N6 coating is additionally fabricated at laser power of 150, 160 and 170 W and a scanning speed of 250 mm/s, the MMCs samples have a relative density of more than 99%. This study demonstrates the possibility of producing dense diamond/N6 and other similar MMCs with appropriate coating, ball milling parameters and LPBF [9].

Effective control of the diamond-metal interface is crucial for achieving optimal performance in metal-matrix/diamond composites. Here, Ti coatings prepared at different pressures were deposited on diamond particles by DC magnetron sputtering. Dia-1.0 was clean and homogeneous, without obvious defects, demonstrating optimal deposition quality and bond strength [10]. The results showed that the microstructure of Ti-coatings depends on the deposition pressure. All surfaces of the coatings had a granular morphology, and increasing the spraying pressure contributed to the grinding of the coating grains. The titanium coating obtained under a pressure of 1.0 Pa was thin and uniform, without obvious defects, demonstrating optimal deposition quality and adhesion density (Fig. 2). In addition, it was determined that the annealing temperature plays a key role in the reaction between Ti-coating and diamond. The TiC phase in Ti-coated diamond particles showed a gradual increase with increasing temperature, and the Ti-coated diamond underwent a complete transformation into TiC-coated diamond at 1000 °C. The experimental results and molecular dynamics simulations showed that the Ti-coating reacted more vigorously with the diamond (100) facet than with the diamond (111) facet at high temperature.

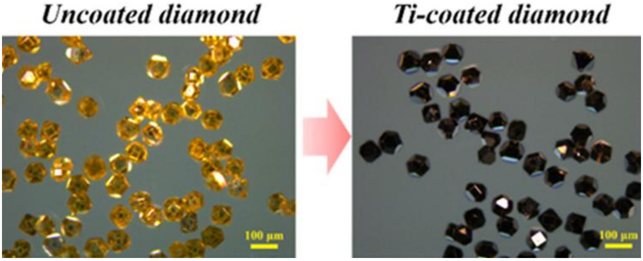

Fig. 2. Uncoated and coated diamonds with TiS [10].

In [11], the authors considered another carbide for coating, vanadium. Diamonds coated with vanadium carbide were produced by the molten salt method. The results showed that, compared to uncoated diamonds, the static compressive strength and oxidation resistance of coated diamonds increased by 42.27% and 158.82 °C, respectively. The vanadium carbide coatings were mainly composed of V_2C and VC. The thickness of the coatings increased with increasing temperature. With increasing relative vanadium content in the raw material, the crystal structure of the vanadium carbide coatings changed from microcrystalline to mesh, and vanadium carbide coatings with microcrystalline structure showed better performance.

To improve the thermal properties of diamond/metal composites, a metal carbide layer is required, which combines both the crystal structure and the heat transfer of heterogeneous interfaces. In [12], experiments were conducted with diamond/Cu–Cr composites to determine the effect of two important variables for thermal diffusion: temperature (800–1025 °C) and holding time (5–60 min), on the growth of chromium carbide interfaces and the resulting thermal conductivity, on the microstructural evolution (Fig. 3) and the corresponding thermal properties of diamond/Cu-0.8Cr composites. In the first stage, Cr dispersed in the Cu matrix diffused from Cu to the diamond surface. Fine flake Cr carbide was formed based on the Cr–C reaction. With increasing holding time or increasing temperature, the flake Cr carbide coalesced into an island structure under surface diffusion, which led to a surface energy difference between the {100} and {111} crystal faces of diamond. When the diffusion of Cr atoms gained further mobility, the "island" structure was finally transformed into a "porous" structure. However, due to the competition between Cr carbides (Cr_3C_2, Cr_7C_3, $Cr_{23}C_6$), cracks may occur between the Cr carbide layer and the diamond surface. When sintering at 900–950 °C for 60 s, Cr carbides are mainly prone to growth and transformed from a "convex" to a compacted structure. The main conclusion of the work [12] is that the optimal sintering condition for the studied diamond/Cu-0.8Cr composites is a temperature of 950 °C for 60 min, at which the sample can reach the maximum relative density (98.11%) and thermal conductivity (577 W/(m•K)).

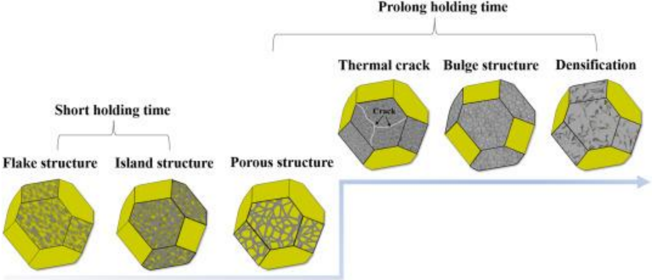

Fig. 3. Schematic diagram of the evolution of the interlayer structure on the surface of a diamond grain with a change in the carbide layer [12].

In the study [13], chemical deposition was used to deposit nickel on the diamond surface. The composite powder was prepared by ball milling, and then the diamond-copper composites were fabricated by rapid hot pressing. The results showed that at a diamond content of 30 vol. %, the composite achieved a thermal conductivity of 467 W/(m•K) with significantly improved interfacial bonding. The successful application of nickel coating by chemical deposition method provided good thermal characteristics of diamond-copper composite. Copper powder with average particle size of 7 μm and nickel-coated diamond particles with average particle size of 120 μm were used as starting materials. These powders were homogenized by ball mill for 2 hours at 180 rpm, after which the uniformly mixed powder was loaded into a graphite mold. The consolidation process included cold pressing the powder compact at 50 MPa for 30 minutes, transferring the compact to a spark plasma sintering (SPS) furnace and vacuuming the chambers to 1.3×10^{-1} Pa. Subsequently, the pressure was applied at a rate of 10 MPa/min until 50 MPa was reached, while simultaneously heating to 800 °C at a rate of 100 °C/min. The temperature and pressure were maintained at 800 °C and 50 MPa for 10 minutes, after which the heating was stopped and natural cooling was carried out to room temperature. The corresponding surface condition of the nickel-coated diamond grain is shown in Fig. 3. Fig. 3 (g) and (h) show diamond particles coated with nickel by chemical deposition. The enlarged image of the nickel coating (h) confirms the formation of a homogeneous, dense and non-porous nickel layer. Based on the results obtained [13], it was found that an excessively long time of chemical nickel plating leads to the formation of a very thick coating, while an insufficient coating time can lead to excessive porosity at the interface between the coating and diamond. Therefore, a coating time of 5 minutes was chosen as the optimal conditions for this study.

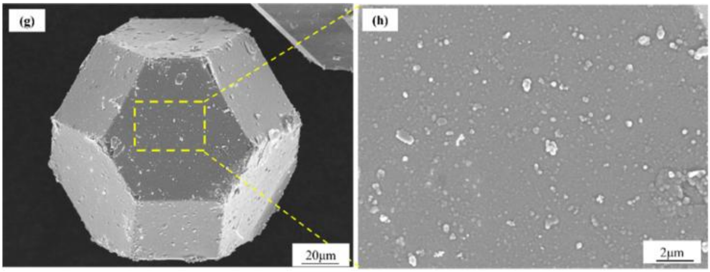

Fig. 3. g: Diamond grain with nickel coating; h: Enlarged image of the surface in Fig. (g) [13].

The above applies to the most common superhard material – diamond, but developments are also underway for a second superhard material – cubic boron nitride (cBN).

Thus, to improve the interfacial bonding between cBN and the SiAlON matrix, suppress the high-temperature phase transformation of cBN, and increase the synthesis density of SiAlON/cBN composites, the surface modification of cBN was carried out by the sol-gel method in this study. Using tetraethyl orthosilicate (TEOS) as a precursor and ammonia solution as a catalyst, a dense sintered SiO_2 coating was deposited on cBN particles. Experimental results show that the sol-gel method successfully deposits a homogeneous, dense, and amorphous SiO_2 shell on cBN particles. The coating thickness shows precise controllability during the multi-cycle coating process (≈30 nm per cycle). For the SiAlON/20 wt.% cBN (coated) ceramic composite obtained using cBN particles after three coating cycles, the interfacial bonding between the cBN particles and the SiAlON matrix is significantly improved, demonstrating appreciable chemical bonding. The fracture mode transforms from intergranular to mixed transcrystalline-intergranular. Compared to the uncoated counterpart, its mechanical properties are significantly improved: the bulk density reaches 3.01 g/cm^3, the Vickers hardness is 17.1 GPa, and the crack resistance reaches 4.76 $MPa{\cdot}m^{1/2}$. This work demonstrates that the application of SiO_2 coating by the sol-gel method is an effective strategy for optimizing the characteristics of SiAlON/cBN ceramic composites [14].

We have already seen above that various coatings are applied to diamonds to protect them or improve their wettability, but diamond itself, in the form of films of microcrystalline or nanocrystalline diamond, is applied to various materials to improve their functional characteristics.

Thus, titanium alloys are widely used in the aerospace industry due to their good comprehensive properties. However, as the scope of application expands, higher requirements are placed on the corrosion resistance of titanium alloys. Due to its natural chemical stability, diamond is a good corrosion-resistant material. Diamond films with three different grain sizes were obtained on the surface of titanium alloys by the method of chemical vapor deposition (HFCVD). The efficiency of substrate protection by three types of films exceeds 90%. The corrosion resistance of nanocrystalline diamond (NCD) films is clearly higher than that of microcrystalline diamond (MCD) films. For NCD films, when the diamond grain size decreases, a cluster structure of particle stacking is formed, which prevents the ingress of aggressive substances to the substrate and additionally increases corrosion resistance [15].

Diamond-coated carbide (WC-Co) milling cutters are widely used for machining graphite or other difficult-to-machine materials. However, improvements in substrate adhesion and cutter life are urgent. In [16], a new electrostatic self-assembly method is demonstrated to solve this problem. The process involves immersing a two-step chemical pre-treated cutter in a specially prepared solution containing deionized water, nanodiamonds (NA) and trimethylammonium chloride. Compared to conventional pre-treatment by scratching or etching, this approach significantly increases the density and improves the uniformity of diamond grains during the nucleation process. As a result of this new approach, it is possible to achieve improvements in both the adhesion of the film to the substrate and the wear resistance of the coated tools. The electrostatic self-assembly process enhances adhesion, which is reflected in the cooling phase. The electrostatic self-assembly etching has the unique ability to prevent direct delamination of the diamond film after growth at a substrate temperature of 920 °C. Cutters with intact MCD (microcrystalline diamond) coating (deposited at 860 °C) pretreated with this new pretreatment process show the longest service life [16].

Finally, let us pay attention to coatings that are applied to hard alloys and steels, and researchers here mainly pay attention to coatings with the presence of titanium, which, as we showed above, has shown its effectiveness in coatings on diamond.

In the study [17], a systematic analysis of the wear phenomenon of TiAlN-coated tools during dry milling of Ti-6Al-4V alloy was carried out. Additionally, the effect of tool wear on the morphology of the machined surface was studied. The results showed that diffusion wear of the tool is defined as the diffusion of Co and W elements outwards. Diffusion wear increases, with the diffusion of Co and W elements being the main cause of diffusion wear of the tool. The diffusion of Ti element is more sensitive to changes in temperature and pressure. During the tool wear process, a synergistic effect between diffusion and adhesive wear was observed. The combined effect of diffusion and oxidative wear weakened the strength of the tool. The main types of defects on the machined surface were grooves, pits, surface tears and sticking. In addition, as the tool wear increased, the chips transformed from conical spiral to arc-shaped, and the degree of sawtoothness of the chips increased [17].

Hard coatings are widely used in materials science as surface coatings to protect mechanical parts subject to friction. For the coating to be functionally successful, it must have high wear resistance. Experimental work was performed on multilayer TiN/CrN coatings with different modulated periods, deposited on XC48 steel substrates with two different surface roughnesses, by the direct current magnetron sputtering method. Their tribological characteristics were investigated after dry sliding wear tests using a tribometer with a “ball on flat surface” contact configuration. The wear mechanisms of TiN/CrN coatings are dominated by oxidation of wear residues and counter-transfer of material. Both decreasing the period thickness and increasing the substrate surface roughness significantly affect the wear rate. Coatings on rougher substrates showed improved wear resistance. However, changing the period thickness of the multilayer layer and increasing the substrate roughness did not lead to a significant improvement in wear resistance [18].

In wind power and other industries, Al_2O_3/TiO_2 coatings are prepared and ground on bearing rings to provide electrical erosion-resistant insulation for high-voltage motors. The wet chemical mechanical grinding (WCMG) process of the hard-brittle Al_2O_3/TiO_2 coating using a combination of a structured diamond abrasive pad and NaOH solution has significant advantages in suppressing crack formation, reducing surface roughness, and improving surface integrity. It is assumed that the mechanism of material removal can be converted from mechanical brittle fracture to plastic removal caused by plastic deformation of the softened surface of the workpiece as a result of the chemical reaction between the NaOH solution and the Al_2O_3/TiO_2 composite. The surface roughness of the coating was reduced from an initial Sa of 3.293 µm to a final Sa of 0.049 µm in the WCMG process with a grain size of 3 µm and pH of 12.01, which is mainly attributed to the plastic removal of the chemically softened coating surface [19]. Fig. 4 illustrates the principle of the WCMG process of the Al_2O_3/TiO_2 composite coating on the bearing ring.

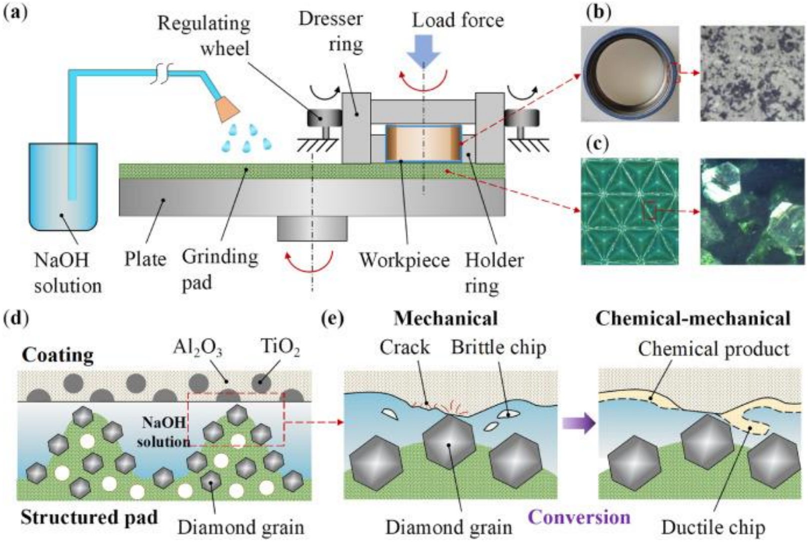

Fig. 4. Schematic diagram of the WCMG process on an Al_2O_3/TiO_2 coating of an insulated bearing, showing (a) the setup, (b) the workpiece, (c) the abrasive pad, (d) the cross-section of the grinding area, and (e) the chemical-mechanical removal of plastic material [19].

The end face of the workpiece is ground on a single-sided lapping and polishing machine using a combination of a structured diamond abrasive disc and NaOH solution. During the grinding process, as shown in Fig. 4(a), an abrasive pad is mounted on the rotating bottom plate of the machine, one end face of the workpiece is placed on the grinding pad, the geometric center of the circular workpiece is limited by the combination of the holder ring, the dressing ring and the position controller, and the workpiece rotates around its geometric center, while a loading force is applied to the other end face of the workpiece, and the NaOH solution is pumped onto the surface of the grinding plate. In particular, there are two areas that appear white and black on the surface of the workpiece coating, containing Al_2O_3 and TiO_2 components, respectively, as shown in Fig. 1(b); in addition, an array structure of triangular pyramidal grooves is fabricated on the surface of the grinding plate, as shown in Fig. 4(c). During the grinding process, the NaOH solution is filled into the grooves of the grinding pad that contacts the surface of the workpiece coating, so that a chemical reaction can be initiated between the NaOH solution and the Al_2O_3/TiO_2 composite, resulting in two advantages as follows. The original hard brittle material on the surface of the workpiece can become softer and can be easily removed, contributing to the increase in the material removal rate. Many surface defects, especially cracks in the Al_2O_3 component area, can be significantly suppressed, explaining that the traditional mechanical removal, which causes brittle fracture caused by micro-cutting of abrasive grains, can be transformed into a term of plastic removal with elastoplastic deformation of softer chemical products under the synergistic effect of mechanical removal and chemical reaction.

Conclusions

Thus, it is possible to draw the following conclusions from the above.

1. In a number of studies, diamond particles are first coated with thin layers of titanium and nickel to ensure a tight interface with the nickel matrix. The wetting of diamond and nickel is improved by applying thin layers of titanium and nickel to the diamond particles.

2. The Ti-coated diamond micropowder was completely covered with a Ni electroplated layer, and the TiC formed between the Ti-coating and diamond provided a stronger interfacial adhesion force compared to that of the Ni-coated diamond micropowder. The titanium coating obtained under a pressure of 1.0 Pa was thin and uniform, without obvious defects, demonstrating optimal deposition quality and adhesion density. In addition, it was determined that the annealing temperature plays a key role in the reaction between Ti-coating and diamond. The TiC phase in Ti-coated diamond particles showed a gradual increase with increasing temperature, and the Ti-coated diamond underwent complete transformation into TiC-coated diamond at 1000 °C. That is, the production of titanium carbide is important.

3. In addition to titanium carbide, other carbides have been used by researchers. For example, B_4C coatings have been successfully synthesized on the surface of faceted diamond crystals by the carbothermic reduction method using a precursor system containing B_2O_3 and B. B_4C coatings consist mainly of rod-shaped crystals, which show preferential deposition on the (110) diamond surface compared to the (111) surface. Furthermore, the thickness of the B_4C coatings increases with

increasing temperature, reaching complete and uniform coverage of both (100) and (111) diamond faces at 1200 °C.

4. Vanadium carbide-coated diamonds were fabricated by the molten salt method. The results showed that compared to uncoated diamonds, the static compressive strength and oxidation resistance of coated diamonds were increased. The vanadium carbide coatings were mainly composed of V_2C and VC.

5. To improve the thermal properties of diamond/metal composites, a metal carbide layer is needed that combines both the crystal structure and the heat transfer of heterogeneous interfaces. Experiments have been conducted with diamond/Cu–Cr composites and the effectiveness of chromium carbides has been proven.

6. In addition to carbides, the effective action of oxides in diamond coatings has also been proven. The mechanism of diamond protection in this study was the predominant oxide donor behavior of Mo–B–C coatings to form a stable oxide layer on the diamond surface. For coatings with low B content, four stages of coating oxidation were observed sequentially with increasing temperature, low-temperature evaporation of MoO_3, stable protection of B_2O_3, and rapid evaporation of B_2O_3. For high-B coatings, the predominant self-reducing flux of B_2O_3 not only suppressed the evaporation of MoO_3, but also provided a reducing environment for MoO_3 to form MoO_2 and Mo_2C with high melting points, which led to the formation of a double synergistic protective oxide layer and significantly enhanced the oxidation resistance of diamonds.

7. Diamond films with three different grain sizes were obtained on the surface of a titanium alloy by the method of chemical vapor deposition (HFCVD). The efficiency of substrate protection by three types of films exceeds 90%. The corrosion resistance of nanocrystalline diamond (NCD) films is clearly higher than that of microcrystalline diamond (MCD) films. For NCD films, when the diamond grain size decreases, a cluster structure of particle stacking is formed, which prevents the ingress of aggressive substances to the substrate and additionally increases corrosion resistance. At the same time, cutters with an intact MCD coating (deposited at 860°C) demonstrate the longest service life.

8. Finally, let us pay attention to coatings applied to hard alloys and steels, and researchers here mainly pay attention to coatings with the presence of titanium, which, as we have shown above, has shown its effectiveness in coatings on diamond, namely TiAlN, TiN/CrN and Al_2O_3/TiO_2.

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АЛМАЗИ З ПОКРИТТЯМИ ТА АЛМАЗНІ ПОКРИТТЯ (ОГЛЯД СУЧАСНИХ РОЗРОБОК)

Анотація. *Покриття зерен алмазів є важливим фактором впливу на зміну їх властивостей та підвищення утримання у зв’язуючому робочого шару шліфувального кругу. Враховуючи, що цей напрямок активно розвивається, в даній роботі нами зупинена увага саме на сучасних напрацюваннях, які є у наукових публікаціях за останні 5 років. Вкажемо, що тут нас найбільше цікавили розробки у напрямку нанесення покриттів на алмазні зерна, які би застосовувалися у абразивних композитах та композитах для різального інструменту, композитах алмаз-метал із підвищеною теплопровідністю, а також особливості нанесення та застосування алмазних покриттів на інструментальних матеріалах. Сучасні дослідження свідчать про ефективність застосування в покриттях на алмазних зернах тонких шарів титана і нікелю, щоби забезпечити щільне поєднання інтерфейсу з нікелевою матрицею. Змочування алмаза і нікелю поліпшується за рахунок нанесення тонких шарів титана і нікелю на частинки алмаза. Карбід титану, що утворюється між Ti-покриттям і алмазом, забезпечує більш сильну силу міжфазного зчеплення у порівнянні з силою алмазного мікропорошку з Ni-покриттям. Для поліпшення теплових властивостей композитів алмаз/метал потрібен шар металічного карбіду, який поєднує як кристалічну структуру, так і тепловий переніс гетерогенних інтерфейсів. У сучасних дослідженнях в покриттях окрім TiC, звертається увага і на інші карбіди: B_4C, V_2C та VC, а також на карбіди хрому. Окремим напрямком є оксидні покриття на алмазах. Механізм захисту алмазів в цьому напрямку уявляє собою переважну окисну донорну поведінку покриттів Mo–B–C для формування стабільного оксидного шару на поверхні алмаза. Алмазні плівки з трьома різними розмірами зерен були отримані на поверхні титанового сплаву методом хімічного осадження з парової фази (HFCVD). Корозійна стійкість плівок нанокристалічного алмаза (NCD) явно вище, аніж у плівок мікрокристалічного алмаза (MCD). Але фрези з непошкодженим покриттям MCD демонструють найбільш довгий термін служби. Звернено увагу на покриття, які наносяться на тверді сплави та сталі, причому переважно дослідники тут надають увагу саме покриттям з наявністю титану, а саме TiAlN, TiN/CrN та Al_2O_3/TiO_2.*

Ключові слова: *алмази з покриттями; покриття нікелем; покриття титаном; карбід титану; карбід бору; карбід ванадію; оксидне покриття; плівки з нанокристалічного алмазу; плівки з мікрокристалічного алмазу.*