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Effect of activators on the properties of nickel coated diamond composite powders

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ABSTRACT

Nickel coated diamond composite powders were fabricated via a newly developed direct electrodeposition technique. The effects of activators on the coating of diamond were firstly investigated and diamond grinding wheels were then prepared from Ni-coated diamond composite powders with different activators. The microstructural characterizations of this composite powders were finally conducted by scanning electron microscopy, energy dispersive spectroscopy, and X-ray diffraction, and the mechanical and tribological properties of as-prepared diamond grinding wheels were also measured. There are changes in microstructures and properties of the composite powders with activators. The activator concentration also has an influence on the morphologies and phase structures of the Ni coating on diamond particles. The composite powders with more compact coating of nickel can be prepared by adding 1 g dm^{-3} or more $AgNO_3$ as an activator to electrodeposit nickel on diamond. The mechanical and tribological properties of diamond grinding wheels were significantly improved when the coating phase structure of Ni crystal grew with (111) plane orientation on the surface of diamond particles. The wheels made from nickel coated diamond composite powders possessed the advantages of easy preparation and outstanding tribological properties. Therefore, Ni coated diamond composite powders exhibit a great potential to be extensively applied in diamond cutting and grinding tools.

1. Introduction

Diamond has become a focus in developing cutting and polishing techniques due to its ultra-high hardness, high thermal conductivity, wear resistance and the thermal expansion coefficient as comparable as the semiconductor [1–3]. Diamond cutting and grinding tools are a group of composite materials consisting of diamond grits and a bonding matrix such as metal or resin. Since the adhesion between abrasives and matrix deteriorates due to the smooth surface and high interfacial energy of diamond abrasives, the diamond grits will be pulled out during grinding, and tools service life will be greatly reduced [4,5].

Many efforts have been made to modify the diamond surface where the electroless plating is an advanced technique used in surface metallization. Chemical depositions have been studied for nickel, cobalt, copper, tungsten and other metal alloys such as Ni-Zn-P [6], Ni-P [7–9], Ni-Cu-P [10] and Ni-W-P [11] on diamond powders. Ahn et al. [8] reported that the elimination of Ni-P fines could improve the adhesion of Ni coating and diamond powders surface. Zhang et al. [12] showed that the low-temperature hot-press sintered diamond/Cu composites produced dual layer structures on diamond particles and exhibited good thermal properties. Yu et al. [13] demonstrated that the adhesion of the diamond particles and the resin matrix could be improved by dense SiC as binder to adhere the diamond particles. Xi et al. [1] used electroless Ni-P plating techniques to coat diamond particles and explored the effects of phosphorus content on the properties of Ni-P coated diamond composite powders, such as surface morphologies, phase structure and heat resistance. Dong et al. [9] reported that the Ni-coated diamond powders via electroless plating technique exhibited higher thermal stability than the diamond without Ni-P coating. Nevertheless, the utilization of electroless deposition is restricted due to the instability of plating solution, high production cost, and environmental pollution.

Compared with electroless deposition, electrodeposition is widely used to fabricate functional coatings due to the distinctive

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advantages of low temperature, high deposition rate and simple controlling condition. Huang et al. [14] used ultrasonic flow plating technique to fabricate Cu-coated graphite powders and investigated the effects of electroplating parameters on the copper content in Cu-coated graphite powders. Zhong et al. [15] discussed the influence of processing parameters, e.g. current density, effective deposition time, pH value and surfactants, on the properties of Co-coated WC powders. Different from those previously reported, diamond was not directly electroplated as a nonconductor. Firstly, diamond powders were basically plated by chemical method and then coating was thickened by electroplating plating or Ni-diamond composite coating was prepared. Sun et al. [16] designed a set-up to chemically plate very thin Ni coating on diamond grain and then thickened the coating by the barrel plating technique. Chen et al. [17] designed a new multi-purpose device to electroplate diamond. After chemical plating a conductive metal on diamond, the metal coating was thickened by electrodeposition in a roller plating device. Selvam et al. [18] introduced a closed-type mini barrel of about 200 cm^3 capacity to electroplate diamond particles with a diameter of 100–250 μm in nickel electrolyte. The Ni-coated diamond composite powders were used to fabricate tipped tools.

Up to now, there are no reports regarding the influence of direct plating of diamond powders and concerning on the coating structure on the friction performance of diamond wheel. In this paper, the diamond was activated by various activators and sensitized by $SnCl_2$ before electroplating. The surface of diamond particles was made to form a layer of conductive film with catalytic activity. Then the Ni-coated diamond composite powders with compact coating were obtained via the direct electrodeposition. The diamond grinding wheel was prepared from the composite powders. The effect of activators on the properties of surface microstructure, phase structure and the adhesion between matrix and the composite powders were studied. The tribological properties of the diamond grinding wheels were measured.

2. Experimental

2.1. Preparation of Ni-coated diamond composite powders

Diamond powders with a diameter of 30–40 μm were supplied by Changsha Huijing Instrument Business Department. Anodic Ni pieces and cathodic Nb plate with purity of 99.9% were purchased from Zhuzhou Cemented Carbide Group Co. Ltd. The chemicals, $NiSO_4{\cdot}6H_2O$, H_3BO_3, NaOH, Na_3PO_4, HNO_3, HCl, $SnCl_2$, Na_2CO_3, Na_2HPO_4, Na_2SiO_3, NH_4Cl, $PdCl_2$, $AgNO_3$, $AuCl_3$, $PtCl_4$ and $RuCl_3$, were analytical reagents and supplied by Sinopharm Chemical Reagent Co. Ltd. Ultra-pure water (resistivity 18.2 MΩ cm) was used in the experiment.

2.1.1. Pretreatment of anode

As a rule, anodic Ni is easily oxidized and passivated due to the formation of a layer of brownish oxides at a high current density. The oxide film should be removed via soaking Ni in diluted nitric acid, and then the pretreated Ni nuggets were used as anode.

2.1.2. Pretreatment of diamond powders

It is necessary to pretreat the diamond powders in order to make them easily coated by Ni. The pretreatment procedures were performed as follows: the diamond powders were immersed in a solution of 20 g dm^{-3} NaOH, 30 g dm^{-3} Na_2CO_3, 10 g dm^{-3} Na_3PO_4, 15 g dm^{-3} Na_2SiO_3 at 90 °C for 20 min to remove surface oil stains → rinsed with ultrapure water → then pickled in 20% HNO_3 at room temperature for 20 min for surface roughness under ultrasonic environment → rinsed thrice with ultrapure water → filtered → then dried in vacuum drying oven at 40 °C. The

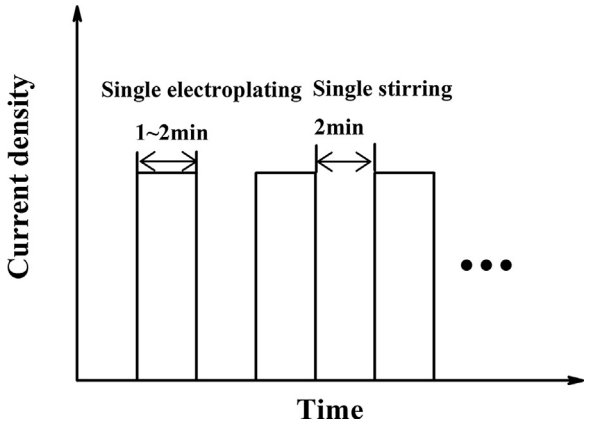

Fig. 1. Schematic model of intermittent electrodeposition.

above treated diamond powders were immersed into the solution containing 10 g dm^{-3} $SnCl_2$ and 40 cm^3 dm^{-3} HCl to be sensitized at 50 °C for 10 min. Next, the diamond powders were ultrasonically activated with five types of activators at 50 °C for 10 min. Finally, the activated powders were soaked in the solution of 30 g dm^{-3} NaH_2PO_2 at room temperature for 10 min.

2.1.3. Electrodeposition process

A house-made electroplating device was used to fabricate Ni-coated diamond powders. Ni electrolyte was composed of 25 g dm^{-3} $NiSO_4{\cdot}6H_2O$, 100 g dm^{-3} NaCl, 30 g dm^{-3} H_3BO_3, and 100 g dm^{-3} NH_4Cl and adjusted to be pH 5.0. Electroplating was carried out in the electrolyte at load of 4 g dm^{-3} diamond powders and cathodic current density of 1 A dm^{-2} at 45 ± 2 °C. The schematic model of intermittent electroplating is shown in Fig. 1.

During electrodeposition, the electrolyte was stirred at a rate of 800 rpm for 2 min before every 1 min electrodeposition pulse and the effective deposition time was set as 20 min. Meanwhile, the 20 cm^3 reducing agent with 30 g dm^{-3} NaH_2PO_2 was dropped into the electrolytes at a feeding rate of 1 cm^3 min^{-1} without stirring in order to increase the efficiency of electrodeposition reaction. After electrodeposition, the products were rinsed with ultrapure water, filtrated and dried at 50 °C in a vacuum oven for 40 min.

2.1.4. Preparation of diamond grinding wheels

At first, the 50 wt% Ni-coated diamond composite powders and 50 wt% phenolic resin were mixed uniformly. Then, the mixture was poured into a steel mold. The steel mold was put into a hot-pressing furnace to be heated at 230 °C for 2 h. Subsequently, the grinding wheels were cooled to room temperature in air. Afterwards, the samples were put into drying oven and heated with a multi-step heating procedure up to 230 °C and maintained for 6 h with air circulation for secondary curing process. Finally, the samples were cooled down to room temperature in furnace.

2.2. Characterization of Ni-coated diamond composite powders

Morphologies and surface composition of Ni-coated diamond powders obtained with different activators were characterized by scanning electronic microscopy (SEM, JSM-6490) and energy dispersed X-ray spectroscopy (EDX). Phase structure of the composite powders were determined by X-ray diffraction (XRD, Shimadzu 6100) with a copper target ($K\alpha$ $\lambda = 0.154178$ nm) performed at 50 kV and a scanning speed of 2° per minute. The coefficient of friction (COF) and the grinding ratio (G-ratio) of wheels were measured using a friction tester (UMT-2MT, CETR, USA) at a frequency of 5 Hz and the peak load of 2 N. The testing of frictional behavior was carried out for 10 min under a dry grinding condition. A sili-

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