Applied Surface Science 258 (2012) 4750–4755

Contents lists available at SciVerse ScienceDirect

Applied Surface Science

journal homepage: www.elsevier.com/locate/apsusc

Hot-filament chemical vapor deposition of amorphous carbon film on diamond grits and induction brazing of the diamond grits

Bojiang Ma*, Qingxian Yu

College of Electromechanical Engineering, Qingdao University of Science & Technology, 266061 Qingdao, PR China

ARTICLE INFO

Article history:
Received 27 March 2011
Received in revised form 8 January 2012
Accepted 12 January 2012
Available online 21 January 2012

Keywords:
Diamond
Hot-filament chemical vapor deposition
Induction brazing
Sharpness
Bonding strength
Chromium carbide

ABSTRACT

The production of a high-quality brazed diamond tool has gradually drawn the attention of the tool industry. Hot-filament chemical vapor deposition (CVD) of amorphous carbon film on diamond grits was conducted. The deposited diamond grits were used to make brazed diamond tools by induction heating. Amorphous carbon film (1–2 μm thick) was deposited onto the diamond surface. The diamond grits protruding from the filler alloy maintain their sharpness after induction brazing of the deposited diamond grits. Discontinuous irregular carbides are distributed evenly on the brazed diamond surface in the filler alloy. This considerably enhances the bonding strength between the filler alloy and diamond grits. Grinding tests of the brazed diamond wheels show a low percentage of pullouts from the matrix and whole grain fracture for the deposited diamond grits brazed by induction heating.

1. Introduction

In recent years, single-layer brazed diamond grinding tools have been developed. These tools can produce many benefits such as high bonding strength between the filler alloy and diamond grits, high grain protrusion from the filler alloy, and large chip storage. However, thermal damage of diamond grits may occur in a long brazing time even under high vacuum or high-purity inert gas. In addition, a highly elevated brazing temperature is needed to improve the wettability of the filler alloy toward the diamond, but it increases the thermal damage risk of the diamond grits.

Induction heating is characterized by local rapid heating. Induction brazing of diamond grits, which is aimed at shortening brazing time, has gradually attracted the concern of the tool industry. Moreover, a brazed diamond tool which is too large to hold in a vacuum furnace can be produced using local induction brazing.

Other methods have been explored to prevent thermal damage of brazed diamond grits. Among these is an active filler alloy with low liquidus temperature [1,2]. The melting temperature of the active filler alloy with low liquidus temperature (e.g., Ag-based alloy containing titanium) is generally less than 950 °C. However, its anti-oxidative ability is too weak to enable much more stringent working conditions compared with that of Ni–Cr alloy presently used in the industry. Diamond surface metallization is another method used to prevent thermal damage of brazed diamond [3]. Diamond surface metallization is characterized by deposition of a layer of strong carbide-forming elements, such as titanium, chromium, and tungsten, onto the diamond surface. The metal coating not only prevents brazed diamond graphitization, but also increases the wettability of the filler alloy toward diamond. However, the method has undesirable effects in alternating electromagnetic fields. First, the metal coating may melt faster than filler alloy. Second, carbon on the diamond grit edges reacts with the metal coating, resulting in blunt edges. Third, these grits move at random because of the electromagnetic force from alternating electromagnetic fields.

In recent years, plasma technology has been used in the manufacturing of amorphous carbon film. Amorphous carbon film can be produced by chemical vapor deposition (CVD) and physical vapor deposition [4,5], but CVD is a more dominantly used method. The amorphous carbon film can be formed on the surface of a diamond grit used as substrate [6,7]. According to Chen and Lin [8], if the carbide layer surrounding the brazed diamond grit is Cr_3C_2, the formation of a 13 μm thick carbide layer consumes 3.7 μm of diamond from its surface. The intermediate carbide layer behaving as a diffusion barrier can reduce the further loss of diamond regardless of the atomic reaction occurring between the deposited diamond grits and Ni–Cr alloy because of the amorphous carbon film on the deposited diamond grits. A qualitative leap in the machinability of the brazed tool can be achieved if the amorphous carbon film can also prevent other types of thermal damages of the brazed diamond

* Corresponding author. Tel.: +86 532 88956068; fax: +86 532 88956068.
E-mail address: mbj2004@sina.com (B.J. Ma).

0169-4332/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
doi:10.1016/j.apsusc.2012.01.074

grits and improve the bonding strength between the filler alloy and diamond grits.

2. Experimental

2.1. Hot-filament chemical vapor deposition of amorphous carbon film on the diamond grits

An alumina-charging tray (50 mm × 20 mm × 4 mm) was used for the hot-filament chemical vapor deposition (HFCVD) on the diamond grit substrate. The substrates were heated by radiating from four hot horizontal tungsten filaments with an interval of 4 mm. The tungsten filaments, with a temperature of approximately 2000 °C as measured by an optical pyrometer, were positioned 5–10 mm above the substrate. The substrate temperature was controlled by adjusting the height of the tungsten filament above the charging tray. The HFCVD device consists of a stainless steel shell, reaction chamber, tungsten filaments, workbench with a water-cooling feature, thermocouple, intake pipe, and water-cooling system.

The substrates were 60-mesh diamond grits with a regular octahedron structure (JR2 tape, Zhengzhou Zhongnan Jiete Superabrasives Co., Ltd., PR China). Prior to the HFCVD process, the diamond grits and charging tray were ultrasonically cleaned with acetone. A single layer of diamond grits (0.1 g) was placed into the charging tray positioned on the workbench. The system was continuously pumped during deposition using a mechanical pump. The gas ratio (H_2/CH_4) used was 100/1.5 sccm, and the total gas pressure was maintained at 2.5 kPa. The substrate was initially heated to 850 °C for 20 min before being lowered to 650 °C for 40 min every time.

The morphology of the deposited diamond grits was examined by scanning electron microscopy (SEM, S-4800, Hitachi-High Technologies, Japan) and characterized by energy dispersive X-ray spectroscopy (EDX, INCAPenta-FETx3, Oxford Instruments, UK), Raman spectroscopy (Renishaw Invia model, Renishaw, UK), and X-ray diffraction (XRD, D/max-2200/PC, Rigaku Corporation, Japan). Raman spectra were excited with the 514.5 nm line of an argon-ion laser. X-ray diffraction was performed on the granule specimens to confirm the new phases with incident rays (Cu target, $\lambda_{K\alpha1}$) of 1.5406 Å.

2.2. Induction brazing of the diamond grits

Diamond grits used as brazed abrasive material are of three types: deposited (diamond grits deposited by HFCVD), Ti-coated, and uncoated diamond grits. Ti-coated diamond grits are the most popular among all the metal-coated diamond grits in the industry. Thus, they were used as the comparative diamond grits in this study. A 1045 steel segment (The area of its end face: about 160 mm^2) was used as the matrix (Fig. 1). A 300-mesh NiCrBSi alloy powder (Cr 15 wt%, B 2.1 wt%, Si 4 wt%, balance: Ni) was used as the filler alloy. Oil and rust were removed from the segment before the brazing process was conducted. The filler alloy powder (110 mg), with an acetone-diluted adhesive, evenly adhered to a segment; 200 diamond grits were then placed evenly on the filler alloy. The brazed diamond segments were made in the device shown in Fig. 2. Heating was conducted using ultrasonic induction power supply at 16 kW output power and 25–35 kHZ oscillation frequency range. The inductor was made of three circles of copper loop with a 34 mm internal diameter. The brazing temperature was measured using the thermocouple whose fire-end was welded on the side of the segment. The brazing temperature was 1050 °C, and the holding time was set to 30 s. The protective gas used (purity: 99.99%) during the brazing was argon. The six brazed diamond segments fabricated using a type of diamond grits were welded on the wheel base at equal intervals and a brazed diamond wheel was fabricated (Fig. 1).

Fig. 1. Brazed diamond wheel.

Each of the different kinds of brazed diamond segments was eroded in strong acid. The brazed diamond grits were then collected after the filler alloy, and the steel substrates were dissolved. The method used in the characterization of the brazed diamond grits was the same method used in the characterization of the deposited diamond.

2.3. Grinding test

The grinding tests were conducted using a remodeled universal tool grinder 3A64 at 5700 rpm rotary speed and 2.1 kW output power. The ground material used was granite with Shore Scleroscope Hardness 85. The granite was face-ground without cooling water. The feeding speed (V_f) and cutting depth (a_p) applied were 1.8 m min^{-1} and 50 μm, respectively.

The diamond grits on the brazed diamond wheel were observed under a stereomicroscope (JSZ4, Nanjing Jiangnan Yongxin Optics Co., LTD., PR China) after every 20 m grinding length starting from the first 20 m.

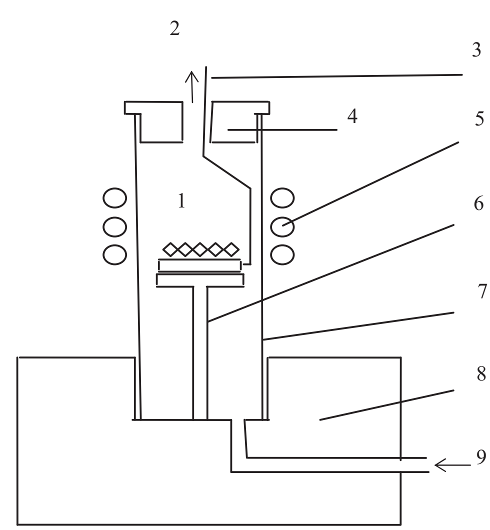

Fig. 2. Schematic of the induction-brazing device. (1) Sample (matrix-filler alloy–diamond), (2) gas outlet, (3) thermocouple, (4) cover with the blowhole, (5) inductor, (6) bracket, (7) quartz tube, (8) pedestal, and (9) gas input.