Journal of Materials Processing Technology 213 (2013) 2163–2173

Contents lists available at ScienceDirect

Journal of Materials Processing Technology

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

Grinding and electrochemical properties of diamond dresser fabricated in a combination technique

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ARTICLE INFO

Article history:
Received 1 May 2012
Received in revised form 11 May 2013
Accepted 23 June 2013
Available online 29 June 2013

Keywords:
Surface-modified diamond
Micro-fabrication
Electroforming
Chemical mechanical polishing
Diamond dresser

ABSTRACT

This study introduces surface-modified diamond grits embedded into nickel micro-prominences via micro-fabrication and nickel electroforming to fabricate novel diamond dressers. Two kinds of diamond dressers with micro-columnar prominences and micro-hemispherical prominences, denoted as CPD and SPD, respectively are characterized and compared with a commercial dresser, BSD. Among them, CPD has the lowest height level of the diamond grits and the diamond height leveling is most uniform due to the columnar shape of the nickel micro-prominences. Therefore, CPD has the highest weight loss of the counterpart and the lowest diamond worn of the diamond dresser by wear tests. In addition, CPD and SPD have a higher corrosion resistance than BSD. The reason is that the nickel deposition has a higher corrosion resistance than the Ni-based alloy in chemical-mechanical-polishing slurry determined by electrochemical impedance spectroscopy and potentiodynamic polarization test. Consequently, this manufacturing process has the potential to simplify considerably the fabrication and integration of surface-modified diamond grits on pad dresser-compatible substrates.

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1. Introduction

Diamonds have several remarkable properties such as high hardness and thermal transfer coefficient. These properties enable the extensive application of diamonds, such as diamond dressers (Tsai et al., 2012; Hintermann and Chattopadhyay, 1992), heat sinks (Jubber et al., 1998; Schubert et al., 2008), and grinding wheels (Yin et al., 2004; Pande et al., 1980; Buttery et al., 1979). Although diamond is an appropriate candidate material for cutting tools, it is inorganic and chemically inert. However, the diamond surface can be immobilized with another material via chemical surface modification. (Tsubota et al., 2005, 2003, 2002a,b,c; Ida et al., 2003).

In the chemical mechanical polishing (CMP) process, the diamond dresser is widely used to recover the texture of the polishing pad surface, which consists of asperities and pores that hold the slurry and abrasives to maintain a constant polishing rate of the counterpart (Hooper et al., 2002; Stein et al., 1996; Park et al., 2008). Nowadays, the conventional diamond dresser is fabricated by electroplating or brazing methods. Although the brazing method firmly fastens diamond grits into a matrix by carbonation (Cr_7C_3 or TiC) occurring at the interface between the diamond grit and matrix, the active element of brazing alloys can serve as a catalyst that causes the degradation of diamond to graphite, especially nickel-based brazing alloy (Huang et al., 2004; Sung and Sung, 2009; Sung, 1999; Hsieh and Lin, 2009; Li et al., 2002a,b). The height leveling of brazing-bonded diamond tips is also not uniform even when the diamond grits are distributed on the flat substrate in regular arrays. The diamond grits of brazed diamond dresser effectively penetrate the work piece by discrete single grit arrangement in the form of array. Hence, they are fragile to the impact force that can result in premature breakage on diamond grits due to the existence of a low amount of working diamond grits (Huang et al., 2004; Hsieh and Lin, 2009). Electroplating is another method for fabricating diamond dressers. When a coating plate is produced from the plating bath suspending the particles, the particles are incorporated into the coating plate. This process is called "composite plating." There are various specific properties of composite plating derived from the incorporated particles. Li et al. (2008) proposed that the incorporation of diamond particles (troublesome diamond) can result in defects in the nickel matrix, such as coarsening matrix grain, inducing gaps between matrix and diamond, promoting emergence of nodules and valleys. However, the incorporation of diamond grits combines the original physical properties of diamond and the characteristic of the functional groups immobilized on the diamond

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0924-0136/$ – see front matter. Published by Elsevier B.V.
http://dx.doi.org/10.1016/j.jmatprotec.2013.06.018

surface (Kim et al., 1995; Matsuoka et al., 1993). Moreover, surface-modified diamond is thus used to improve the corrosion resistance of the conditioner by improving the integrity of the diamond/nickel interface. Therefore, there are numerous studies on composite electroplating (Benea et al., 2002; Reddy et al., 2000; Wang et al., 2000; Chang et al., 1998). Although the electroplating method produces various curves at fast cutting speeds and low cost, the diamond grits are mechanically trapped into a nickel matrix (Lin and Kuo, 1998). After suffering from the impact force, they are easily pulled out and the dresser life is shortened.

In recent years, a number of approaches for improving diamond dresser manufacturing have been proposed in Tsai et al. (2009) prepared a polycrystalline diamond as an abrasive material in the form of pyramids or shaving blade by the sintering method (Tsai, 2010). They also propose a combinatory concept of using several 2 in.-diameter brazed diamond dressers integrated into a 12 in.-diameter disk as a differently arranged diamond dresser (Tsai et al., 2010). Kim and Kand (2011) have prepared a CVD-synthesized diamond film on a Si3N4 substrate composed of a patterned cube array formed by the creep feed grinding method to investigate the effects of slurry corrosion and diamond drop-off. Luo et al. (2007) have used a LIGA-like process to prepare a diamond dresser. The active components for dressing are composite electrodeposits that consist of a nickel matrix, and those for lapping are nano-sized diamond particles. However, a lapping tool with a micro nickel/diamond abrasive pellet has not been tested for its wear resistance. The active components of such a lapping tool, whose pellets are also nickel/diamond composites, differ from the sharp cutting edges of diamond grits in a diamond dresser. However, a few reports have mentioned methods of integrating micro-fabrication and surface-modified diamond grits into a diamond dresser.

This study proposes a combined micro-patterning and nickel electroforming method for fabricating a novel diamond dresser with nickel micro-prominences composed of surface-modified diamond grits. This method not only enhances the thickness uniformity of nickel deposit, but also precisely controls the uniformity of the distribution and height level of surface-modified diamond grits. Improved bonding strength between diamond grits and nickel deposit are derived from smoothing deposits via incorporating the surface-modified diamond grits with hydrophilic properties into nickel deposit. The nickel micro-prominences also provide higher densities of working surface-modified diamond grits to share the impact force and extend the dresser life.

2. Materials and methods

2.1. Brief description of manufacturing procedure

The whole experimental procedure is shown in Fig. 1. The experimental procedure divided into two parts including the fabrication of novel diamond dresser and the surface modification of the diamond surface. Typically, the surface modified process consists of three steps as below. (a) As-received diamond grits were firstly cleansed by immersing with 38% HNO_3 at 80 °C for 4 h. (b) Secondly, the cleansed grits were immersed in a $HF+HNO_3$ mixed acid solution (1:1 mixture by volume percentage) at room temperature for 4 h, and then rinsed with deionized (DI) water. (c) Finally, the diamond grits were immersed in a $H_2SO_4+HNO_3$ solution (1:1 mixture by volume percentage) at 80 °C for 4 h after drying, and then followed by rinsing with DI water and oven drying. On the other hand, the fabricating procedure of the diamond dresser is simple described as below. A 316L stainless steel is polished as a dresser substrate and then, a resist mold is coated on the stainless steel as the patterned mold. Consequently, the characteristics of the diamond-nickel composites formed by the electroforming are investigated. The fabrication procedures and details of each step are described below.

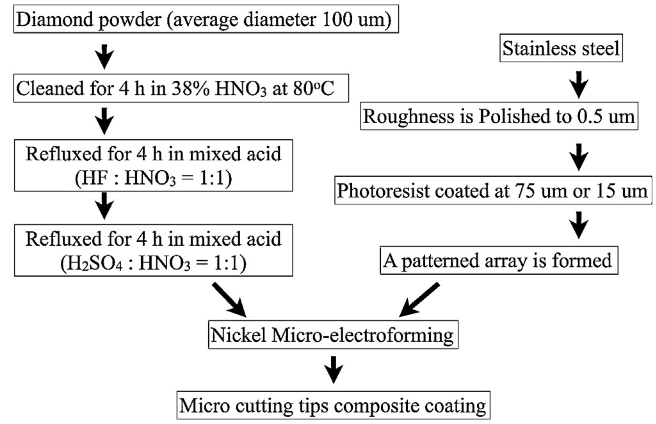

Fig. 1. Experimental scheme of this study.

2.2. Surface modification of diamond grits preparation

Commercial synthetic diamond powders (Diamond Innovations USA, MBG 600; average diameter 100 μm; sharp type) were used as the abrasive particles for the diamond dresser. To obtain the desired functional group on the diamond grits, oxygenated diamond was prepared in accordance with previous studies (Tsubota et al., 2005, 2002a,b,c).

The functional groups on the diamond grits were identified via a diffuse reflectance Fourier-transform infrared (FT-IR) spectroscopy system (Varian 640-IR FT-IR spectrometer, Agilent Technologies). To compare the carbonization effect on the modified diamond surface, two commercial brazing alloys, a Ni-based alloy ($HBNi_2$: Ni–3Fe–7Cr–3B–0.5Si–0.02C) was used as braze materials and detected by micro-Raman spectroscopy (He–Ne laser type: $\lambda = 633$ nm, Nicolet Almerga XR; BX-51, Olympus). The water-shedding qualities were evaluated by face contact angle meter (Contact angle goniometer, Sindatek model 100SB, Japan). The surface-modified diamond grits were then ready for use in the fabrication of diamond dressers.

2.3. Fabrication of diamond dresser and substrate pretreatment

2.3.1. Design route of diamond dresser

Several factors were studied to optimize the properties of diamond dressers, including the appropriate photoresist mask, dimensions of diamond grit, and geometry of diamond cutting tips. The photoresist mask was formed to arrange the plurality of diamond grits in an array to form well-controlled micro-columnar prominences with diamond grits. In general, the mask thickness was 1/3–2/3 times the diamond grit diameter, and the diameter of the pattern aperture was 1–1.5 times the diamond grit diameter. These conditions ensured that the diamond grits were upright in the substrate and more working diamond grits were at the interface during pad dressing. Therefore, the mask thickness, diameter of the pattern aperture, and distance between two adjacent pattern apertures were set to be 75, 285, and 500 μm, respectively, by considering the diameter of the surface-modified diamond grits.

2.3.2. Fabrication of the novel diamond dresser

The manufacturing process has three main parts as shown in Fig. 2. Firstly, an appropriate substrate is manufactured: (a) a 316L stainless steel substrate (diameter = 100 mm; thickness = 1 mm) was polished to a roughness of around 0.5 μm (*Ra*), and cleansed with DI water in an ultrasonic cleaner to remove impurities on the