Int. Journal of Refractory Metals and Hard Materials xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Int. Journal of Refractory Metals and Hard Materials

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

Study of brazed diamond micro-powder burs fabricated using induction brazing with either an amorphous or a crystalline Ni-based filler alloy

Bojiang Ma *, Guanglei Yang, Fanning Bu

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

ARTICLE INFO

Article history:
Received 11 September 2016
Received in revised form 7 October 2016
Accepted 16 October 2016
Available online xxxx

Keywords:
Amorphous Ni-based alloy
Crystalline Ni-based alloy
Diamond micro-powder
Brazing
Grinding performance

ABSTRACT

The outcome of brazing diamond micro-powder using a crystalline Ni-based alloy is not ideal because of the relatively high melting temperature and relatively poor wetting of the crystalline Ni-based alloy toward the steel substrate. In this study, a brazed diamond micro-powder bur was fabricated using an amorphous Ni-based alloy. Fine grains with an average diameter of about 0.02–0.03 μm are formed during the heating process of the amorphous Ni-based alloy. The melting of 0.2 g filler alloy stacked at the center of a circular steel disc indicates that, after heating above the melting finish temperature for 20 s, the wetting ability i.e. wetting area of the amorphous Ni-based alloy for a steel substrate is 1.34 times larger than the wetting ability of the crystalline Ni-based alloy. Unlike diamond particle brazing using a crystalline Ni-based alloy, the diamond particles brazed with the amorphous Ni-based alloy can be better exposed and the brazed surface can also maintain its original shape. In addition, the brazed diamond micro-powder bur obtained using induction brazing with amorphous Ni-based filler alloy can be dressed more easily. The grinding efficiency of the dressed diamond micro-powder bur fabricated using induction brazing with the amorphous Ni-based filler is significantly higher than that of the dressed diamond micro-powder bur fabricated using induction brazing with a crystalline Ni-based filler alloy.

1. Introduction

Electroplating and brazing are commercial fabrication methods commonly used to produce diamond tools. Unlike electroplating, brazing can accomplish metallurgical bonding between the binding agent and the diamond grains or the substrate [1,2]. Brazed diamond micro-powder tools can be used for precision processing of optical crystal chips, super-polishing (or surface modification) of large silicon wafers, polishing (or carving) of high-grade stone, car glass, ceramics, cemented carbide, and magnetic materials. These processes require to be high precision for ultra-thin processing.

Because of the presence of a synthetic catalyst and a high specific area [3], man-made diamond micro-powder is more prone to oxidative deterioration than a large man-made diamond grit at high temperature. The use of a filler alloy with a low melting point and short heating time are also ways to braze diamond micro-powder. The initial melting temperature of filler alloys with low melting points, such as Cu- and Ag-based filler alloys, is usually below 800 °C [4]. The drawback of a filler alloy with low melting point is low hardness and a high wear rate. As a result, filler alloys with low melting points are seldom used today. Hence, short-time heating has become the preferred method to braze diamond micro-powder. High-frequency induction heating is a variation of short-time heating. It can increase the work piece temperature to 50 °C/s.

Because of its high hardness and containing the active element Cr, NiCrBSi alloys have become popular filler alloys to braze diamond [5,6]. Crystalline NiCrBSi alloy consists of a crystalline solid solution and compound. Its chemical bonds only break at higher temperatures. This is unfavorable for fast wetting of liquid filler alloy on substrates and diamond grits. It is also unfavorable to avoid thermal damage of diamond micro-powder. The microstructure of amorphous NiCrBSi is similar to the one of a liquid metal. Amorphous NiCrBSi has no solid solution and compound. Its microstructure is even and shows no composition segregation [7]. Even if a part of its microstructure can be turned into a crystal, the crystal grains remain very small, nano-sized [8,9]. Therefore, amorphous NiCrBSi alloys show a lower initial melting temperature and a narrow melting temperature range. Melted amorphous NiCrBSi alloys can quickly wet both diamond grits and substrates at low temperature. This makes a short brazing time possible, and avoids thermal damage of the diamond.

In this study, we brazed diamond micro-powder on a 45-steel substrate using induction heating with either amorphous NiCrBSi or

* Corresponding author.
E-mail address: mbj2004@sina.com (B. Ma).

http://dx.doi.org/10.1016/j.ijrmhm.2016.10.023
0263-4368/

crystalline NiCrBSi, in an inert gas atmosphere. Subsequently, the differences in their microstructure and grinding performance were investigated.

2. Experimental

2.1. Materials

Synthetic diamond powder (30–60 μm; Zhengzhou Zhongnan Jiete Superabrasives Co., Ltd., China) was chosen as test material. The filler alloy was 300-mesh amorphous NiCrBSi alloy powder and 300-mesh crystalline NiCrBSi alloy powder (Cr: 7.5 wt%, B: 3.1 wt%, Si: 3.5 wt%, balance: Ni). The substrate was 45 steel.

2.2. The brazing process

The filler alloy (crystalline or amorphous) and the diamond powder (mass ratio: 6 1) were mixed evenly. They were stirred into a paste using diluted acrylic adhesive (acetone/oily-acrylic-adhesive ≈ 1/20). The paste was evenly coated on a 45-steel cylinder (diameter: 6 mm; length: 80 mm) from the top. The coating was 12 mm long and about 100 μm thick.

The brazing equipment was a supersonic-frequency induction heater with 16 kW output power. The samples with pre-coated amorphous filler alloy were heated to 1000 °C for 20 s, and the samples with pre-coated crystalline filler alloy were heated to 1050 °C for 20 s. A high sensitivity infrared thermometer with a maximum range of 1500 °C was used to measure the heating temperature. Argon (purity: 99.99%) was used to protect the samples in the brazing process.

2.3. Physicochemical characterization

The D/MAX-RB X-ray diffractometer (Rigaku Corporation, Japan) was used to analyze the phases of the filler alloys. The X-ray tube voltage and the X-ray tube current were 40 kV and 100 mA, respectively. The incident wave was taken from the K_α spectrum (1.5406 Å) of a Cu target. The scanning rate was 4°/min.

A model DZ3320A differential thermal analyzer (DTA) (Nanjing Dazhan Institute of Electrical and Mechanical Technology, China) was used to analyze the melting range of the amorphous NiCrBSi alloy and the crystalline NiCrBSi alloy. Its heating rate was set to 20 °C/min and its maximum testing temperature was set to 1150 °C.

The wettability of the filler for 45-steel substrate was observed using the area spreading method (test method of wettability for brazing filler metals, GB/T 11364–2008, China). In the tests, 0.2 g of filler was stacked in the 8-mm-diameter circle at the center of 45-steel disc (ϕ35 mm). The surface roughness (R_a) of the discs was 2.5 μm. Argon was used to protect the materials during the tests.

A model JSM-6300 scanning electron microscope (SEM) was used to observe the morphology of the brazed diamond micro-powder coating. Some brazed diamond micro-powder samples were immersed in aqua regia (hydrochloric acid (1.19 g cm^{-3})/nitric acid (1.4 g cm^{-3}) = 3/1). Diamond particles dropping with erosion were cleaned using acetone and the particles were observed with an SEM.

2.4. Dressing of brazed diamond micro-powder burs and their grinding performance

As shown in Fig. 1, SiC oilstone was used to dress brazed diamond micro-powder burs in a small CNC machine (main motor power: 4 kW). The dressing speed was 3000 rpm. The normal pressure of oilstone toward burs was 10 N. A model 4XC inverted metallurgical microscope (Shanghai Optical Instrument Factory, China) was used to observe the surface of the burs dressed.

The test equipment to measure grinding performance included also a small CNC machine (grinding speed: 5000 rpm). The test material was

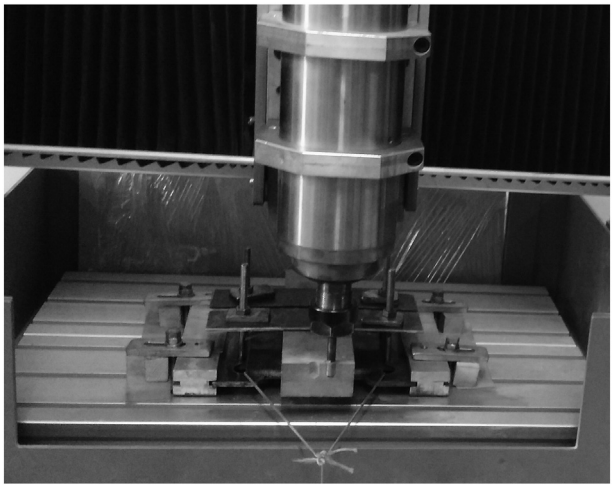

Fig. 1. Dressing device for the brazed diamond micro-powder bur.

6-mm thick ceramics (shore hardness: 90). The burs cylindrically ground the ceramics. The test device was similar to the dressing device and the normal pressure of oilstone toward burs was also 10 N.

3. Results and discussion

3.1. Characteristic of the filler alloy

Fig. 2(a) is the X-ray diffraction (XRD) trace of the NiCrBSi alloy that is initially amorphous and then heated to 880 °C for 45 s. Fig. 2(b) is the X-ray diffraction (XRD) trace of crystalline NiCrBSi.

According to the Scherrer equation [10]:

$$L = \lambda/(\beta cos\theta) \quad (1)$$

where L is the scale of coherent scattering area that may approximately be taken as the size of a formed crystal grain; λ is the wave length of incident ray; β is the full width at half maximum of diffraction peak and its unit is radian; θ is the glancing angle. The full half maximum of the higher diffraction peaks in Fig. 2 was used in the equation. The calculated results show that the average crystal grains formed through the crystallization of the amorphous filler alloy is about 0.02–0.03 μm, but the average crystal grains of the crystalline filler alloy is 1 μm.

In other words, the crystal grains formed during heating are inevitably fine because the microstructure of the amorphous filler alloy is even and does not segregate. Furthermore, atoms in the solid diffuse difficultly. Such fine crystal grains can quickly melt or decompose. As a result, physical wetting by the amorphous filler of diamond grits or substrates occurs fast.

The essence of the melting of the filler alloy is the melting of the solid solution and the decomposition of the compound. Fig. 3 shows the DTA curves for the crystalline filler alloy and the amorphous filler alloy. It is obvious that crystallization takes place between 443.6 °C and 593.3 °C in amorphous NiCrBSi alloy. The initial melting temperature of the amorphous filler alloy is 913.8 °C and its finishing melting temperature is 993.7 °C. The initial melting temperature of the crystalline filler alloy is 933.7 °C and its finishing melting temperature is 1044.1 °C. The amorphous filler has a lower initial melting temperature. In addition, its melting range (79.9 °C) is 30.5 °C lower than for the crystalline filler (110.4 °C). This phenomenon is inseparable from the fine grains formed during the heating of the amorphous filler. The fine grains can melt quickly, when heated above the initial melting temperature.

To obtain better fluidity of the liquid filler and to develop the effect of every composition of filler alloy, the brazing temperature should be chosen according to the final melting temperature of the amorphous filler and the crystalline filler. Therefore, the brazing temperature of

Please cite this article as: B. Ma, et al., Study of brazed diamond micro-powder burs fabricated using induction brazing with either an amorphous or a crystalline Ni-based fi..., Int J Refract Met Hard Mater (2016), http://dx.doi.org/10.1016/j.ijrmhm.2016.10.023