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Microstructure and performance of diamond abrasive grains brazed in mesh belt furnace with ammonia dissociating atmosphere

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ABSTRACT

In order to achieve the mass production of the brazing diamond tools, brazing of diamond grains to the matrix using Ni—Cr active filler alloy was investigated in the mesh belt furnace, which could realize uninterrupted brazing under ammonia dissociating atmosphere. The surface characteristics and interfacial microstructures of brazed diamond in mesh belt furnace were analyzed by scanning electron microscopy and energy dispersive X-ray spectroscopy. The residual stress, static compressive strength and impact toughness of the brazing diamond were measured and the corresponding results were compared to the brazing diamond grains in vacuum furnace. Results demonstrated that chemical reaction occurred between the diamond and filler alloy. The compound composed of Cr_3C_2 and Cr_7C_3 was formed at diamond interface and a higher bonding strength was obtained. The residual stresses of brazing diamond in mesh belt furnace were lower than that in vacuum furnace in the case of identical protruding height. However the static compressive strength and the impact toughness were higher than that in vacuum furnace.

1. Introduction

Diamond with high hardness, wear resistance and chemical stability is widely used to fabricating cutting tools (e.g. diamond grinding wheel, diamond blade saw and diamond drilling bore), which are used to machine the hard and brittle materials, such as cemented carbide, natural stone and concrete, et al. [1]. Nowadays diamond tools are practically manufactured by sintering, electroplating and brazing method.

Diamond is difficult to wet because of its chemical inertness, so it is difficult to acquire a strong bonding strength between the diamond and the matrix in sintering condition, even if surface metallization of the diamond and adding active element (e.g. Cr, W, V and Ti) to the substrates are developed [2–6]. Meanwhile, the diamond grains are mechanically embedded by nickel (Ni) in electroplated diamond tools, hence the holding force between the abrasive grains and matrix is not enough as well. The grains of brazed diamond tools are firmly joined to substrates because of strong chemical bonds between the grains and the filler alloys [7–9]. Therefore brazing technique could solve the problem of premature pullout, which is regarded as a major shortcoming of electroplating diamond tools [10]. Moreover, diamonds in single-layer brazed tools can be shallowly buried in the brazing alloy. As a consequence, the protrusion height of diamonds is higher and more space for coolant flow produces, which improves not only the cooling and the storage of the chips [11,12], but also the cutting speed and tool service life [13,14]. In recent years, the research upsurge of the brazing diamond was gradually increased due to its excellent cutting property. However, previous studies focused on microstructure formation, interface characterization at the joint of abrasive grains and brazing alloy, or thermal damage on the diamond under the condition of vacuum and induction heating [15–20]. There has been less research on the subject of how to improve the productivity of the brazing diamond tools on the basis of ensuring the quality and in turn realize the mass production of brazing diamond tools.

In fact, the process of brazing diamond by vacuum furnace or induction heating has somewhat limitation respectively. The brazing atmosphere can be controlled effectively in vacuum furnace, but it takes a long heating and cooling time. In addition, the volume of vacuum furnace is limited, which results in small batch production. The induction brazing has the advantages of shorter heating time and smaller heat-affected zone, while the brazing temperature is difficult to control. Furthermore, the induction brazing cannot be used to mass production because of its technical feature. Therefore, the mass production of brazing diamond tools cannot be realized through the above methods.

In order to solve this problem, this paper intended to explore the brazing process of continuous heating in mesh belt furnace with the ammonia dissociating protective atmosphere. Mesh belt furnace, which has been utilized to brazing of cement carbide and carbon steel extensively [21], can facilitate the large-scale batch production

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continuously. However, nowadays there are almost no relevant reports on the application of brazing diamond.

In this study, brazing diamond tools were fabricated with Ni—Cr filler alloys in mesh belt furnace with ammonia dissociating protective atmosphere. Subsequently, the surface characteristics, interfacial microstructures and residual stress of brazing diamond were analyzed. Finally, the static compressive strength and impact toughness for the brazing diamond after chloroazotic acid etching were measured and compared with the diamonds brazed in vacuum furnace.

2. Materials and experimental procedures

The commercial Ni—Cr (78.5 Ni—12 Cr—4 Fe—3 Si—2.5 B, wt.%) filler alloy powders, diamond and steel substrates composed of 0.45% C were used in the experimental process. Diamond (Huanghe Whirlwind Co. Ltd., China) with sizes ranged from 297 μm to 350 μm were used. The filler alloy powder was made into paste through adding resin glue. The substrate was machined into the trial samples with sizes of 20 mm × 10 mm × 5 mm.

The diamond grains were ultrasonically cleaned in acetone to remove the impurities. The paste-shaped filler alloy was covered on the substrate sample evenly with the thickness about 200 μm. Then the diamond grains were arranged on the filler alloys. Thus, the raw materials were assembled into three-layered structure of diamond grits-filler alloy-substrate.

The brazing samples were placed in mesh belt furnace with ammonia dissociating atmosphere and heat-treated at 1100 °C for 15 min. The running speed of mesh belt was 82 mm/min, the gas flow of protective atmosphere entering into the heating chamber was 4 m^3/h, and the pressure of cooling water was 0.035 MPa. Other samples were put into the vacuum furnace with the vacuum degree of no $>10^{-2}$ Pa, and heated to 1020 °C for 18 min.

Fig. 1 illustrates the schematic of mesh belt furnace, which contains feeding zone, heating zone and cooling zone. The protective atmosphere was used in heating zone includes hydrogen and nitrogen decomposed by liquid ammonia, the equation is:

$$2NH_3 \overset{catalyst}{\rightarrow} N_2 + 3H_2 \quad (1)$$

The dew point could reach −60 °C after the mixed gas of the hydrogen and the nitrogen produced by ammonia decomposition was purified by highly-efficient molecular sieve. The purified gas entered into the heating zone, and excluded the air in the mesh belt furnace. Then the protective atmospheres were ignited, and flame screen came into being at the entrance and the exit of heating zone, which could prevent the outside air from entering the heating chamber and protect the brazing sample against oxidation. Double water jacket structures were made for the cooling zone. When fabricating the diamond, test samples were placed on the mesh belt driven by electric motor and passed through the feeding zone, heating zone and cooling zone successively, thus the brazing processes of the diamond tools were finished.

The interfacial microstructure of the diamond and elemental distribution of the joining interface were observed by scan electron microscope (SEM, Hitachi-4800, Tokyo, Japan) coupled with energy-dispersive X-ray spectrometry (EDS). The interfacial resultant of diamonds after chloroazotic acid etching was detected by X-ray diffraction (XRD, Bruke AXS D8 Advance, Germany).

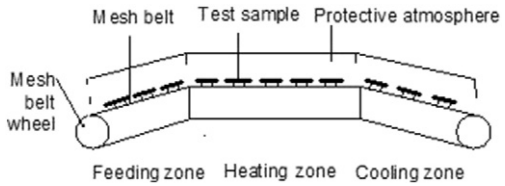

Fig. 1. The schematic of mesh belt furnace.

The surface nature of brazing diamond protruding out of the filler alloy was observed and the residual stresses in the diamond after brazing were measured using laser Raman microscopy (Renishaw Invia, Nd-YAG laser type, wave length 532 nm, England). Raman scatter peak reflects the vibration spectra characteristics of materials. When the laser beam of the microscope is focused on the point on the diamond under compressive stress, the Raman-Stokes peak in Raman spectra shifts to a higher wave number compared with the wave number of Raman-Stokes peak under unbrazed and stress-free diamond grits. When the laser beam is focused on the point of diamond grits under tensile stress, the peak shifted to a lower wave number. So the stress state of brazed diamond can be determined by Raman-Stokes peak position [22].

DLY-92 static strength measuring equipment was applied for checking the static strength of diamond grits after chloroazotic acid etching. Forty grits were measured and the mean maximum static load P was calculated. In accordance with the literature [23], the static compressive strength σ (MPa) of the diamonds after chloroazotic acid etching was determined as follows:

$$\sigma = 1.37P/d^2 \quad (2)$$

where P was the mean static load of diamond grits after chloroazotic acid etching and d was the mean diameter (mm) of the diamond grits after chloroazotic acid etching.

Impact toughness of diamond grits after chloroazotic acid etching was measured using CM-II super-hard abrasive grains impact toughness measuring equipment. The rotating speed of measuring equipment is 2400 r/min. A group of diamond grits weighing 0.4 g was impacted for 2000 times. After impacting, the diamonds were sieved through a 60-mesh screen. The unbroken ratio (TI) of the diamond grains after chloroazotic acid etching was calculated as follows [23]:

$$TI = \frac{m_1}{m} \times 100\% \quad (3)$$

where m_1 was the mass of remained diamonds after impacting and sieving (g), and m was the mass of diamonds before impacting (g). The measurement above was repeated three times and a average value of TI was determined as the impact toughness of diamond after etching.

3. Results and discussion

3.1. Surface and interface

The surface morphology of diamond grains brazed in mesh belt furnace with ammonia dissolving atmosphere was shown in Fig. 2. It can be seen that the filler alloy climbed well along the diamond surface, which demonstrating good wettability of Ni—Cr alloy toward diamond at the brazing ambient of ammonia dissociating atmosphere. Each diamond grains had clear edges and smooth surface, it can be inferred that protective atmosphere had no effects on the surface of diamond protruding out of the filler metal.

In ammonia dissolving atmosphere, nitrogen was an inert gas, which wound not react with carbon (C). However, hydrogen erosion exists possibly in high temperature, which can be explained as the following reaction may occur:

$$xC + yH_2 \rightarrow C_xH_{2y} \quad (4)$$

In general, the enthalpy change of chemical reaction is negative ($\Delta H < 0$), so the case for the entropy change ($\Delta S < 0$). The variety of Gibbs free energy for the reaction ($\Delta G = \Delta H - T\Delta S$) has a critical temperature ($T_0 = |\Delta H/\Delta S|$), which means $\Delta G = 0$ in this temperature.