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Effects of process parameters on interfacial microstructure, residual stresses, and properties of tunnel furnace brazed diamonds

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ABSTRACT

Diamonds were brazed on the substrate with nickel-chromium (Ni—Cr) filler alloy at a certain temperature for three different mesh belt speeds in the mesh belt continuous tunnel furnace, respectively. In this study, a different perspective involving the exploration of the new processes was used that could allow for the mass production of brazed diamond tools. The interfacial microstructure between the diamonds and filler alloy was analyzed by scanning electron microscopy, energy dispersive spectrometry, and X-ray diffraction. The residual stresses and mechanical properties of the brazed diamonds were determined through the laser Raman spectrum and the compressive strength or impact toughness testing equipment for superabrasives, respectively. The results illustrated the occurrence of chemical reaction at the interface of the filler alloy-diamond followed by the formation of the Cr—C compound. Moreover, the thickness of the interfacial reaction layer increased with the decrease in the mesh belt speed. The brazing high temperature and development of the Cr—C layer were found to be responsible for the residual stresses in the diamonds. The mechanical properties of the brazed diamond grits strongly depended on the resultant thickness of the diamond surface and the residual stresses produced during brazing.

1. Introduction

Diamonds are often utilized as abrasive components for cutting or grinding tools, owing to their high hardness, favorable strength, and wear resistivity [1,2]. The diamond tools are fabricated by attaching the diamond abrasive grains to the metal substrates via the bonding agent. According to the bond type, monolayer diamond tools are divided into the following three types: the resin-bonded, the electroplated, and the brazed tools, among which, mechanical bonding exists between the diamonds and the substrates in the first two types of diamond tools. Moreover, chemical bonding occurs at the interfaces of diamonds to substrates in the brazed diamond tools. Compared to the resin-bonded and electroplated diamond tools, the abrasive grains of the brazed diamond tools can be firmly fixed on the substrates. A lower proportion of the diamond grit can be buried in the filler alloy for the brazed diamond tools and this leads to an additional space for chip accommodation, which improves the heat loss. Owing to the above mentioned advantages, the brazed diamond tools are apparently superior to the traditional electroplated or resin-bonded diamond tools in both service life and cutting efficiency [3,4].

Currently, the fabrication of brazed diamond tools in the industry is carried out mainly by heating in a vacuum resistance furnace. This brazing method possesses several merits, such as self-deoxygenation, self-purification, use of cleaner and more compact molten filler alloy, uniform product quality, and repeatable process [5]. Moreover, in this method, the atmosphere can be effectively controlled and a small batch of tools can be brazed every time [6]. However, vacuum brazing requires the longer heating durations and slower cooling rates, which lead to low productivity [7]. The present research mostly revolved around several aspects, such as the improvement of the interfacial microstructure or reduction of the thermal damage of the vacuum brazed diamond tools [8–11]. These have not been reported in the related study of technology and mechanism for productivity increase of brazed diamond tool.

In order to improve the production efficiency of brazed diamond tools, a novel brazing process was explored. In this process, the diamond tools are brazed in a mesh belt continuous tunnel furnace under ammonia dissociating atmosphere, which even helps in the large-scale production of brazed diamond tools. Fig. 1 shows the schematic illustration of the mesh belt continuous tunnel furnace, which consists of the feeding zone, the heating zone, the cooling zone, and the output zone. Prior to brazing, the mixture of dissociated ammonia gases (N_2,

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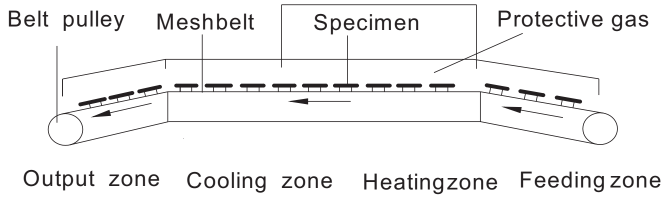

Fig. 1. The schematic illustration of the mesh belt continuous tunnel furnace.

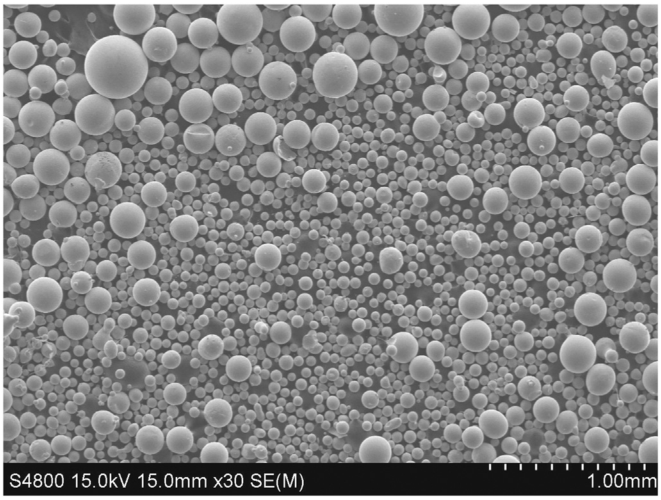

Fig. 2. Power of Ni—Cr active filler alloy.

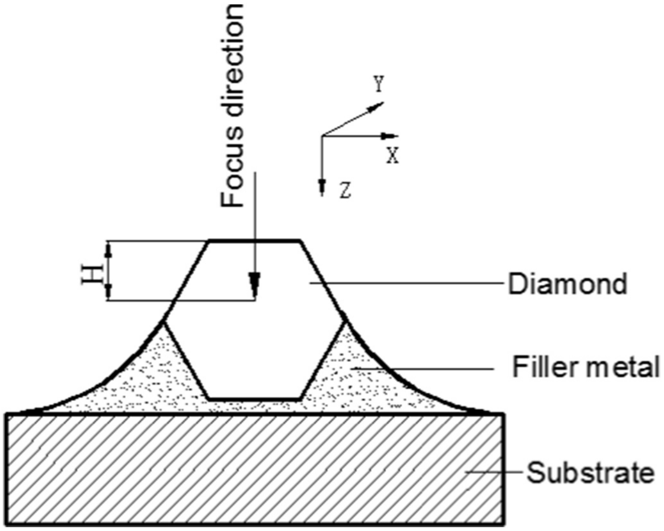

Fig. 3. The schematic illustration of measurement of residual stresses by Raman spectroscopy.

H_2) is filled into the tunnel furnace in order to eliminate the air present in the furnace. Then, the equipment is heated to the temperature required for the brazing technology. For brazing, the prepared specimens (three-layered structure of diamonds-filler alloy-substrates) are placed on the mesh belt of the feeding zone, which is driven by an electric motor, successively passing through the feeding zone, the heating zone, and the cooling zone to the output zone. Subsequently, the work piece brazing can be finished. This process decreases the auxiliary time, such as vacuum pumping at prophase and cooling at a later stage of vacuum brazing, due to the adoption of the continuous heating method during brazing. Correspondingly, the productivity increases.

In this study, diamonds were brazed on the steel substrate with nickel-chromium (Ni—Cr) filler alloy in the mesh belt tunnel furnace under the ammonia dissociating atmosphere. Furthermore, the cutting performance of the brazed diamond tools was found to be strongly depended on the interfacial microstructure, residual stresses, and mechanical properties of the diamond abrasive grains subsequent to brazing, which in turn were strongly affected by the brazing parameters [12]. For the tunnel furnace, the mesh belt speed (determining the holding time, and denoted as belt speed) is a significantly important brazing parameter. The main objective of the present study was to identify the practicability of tunnel furnace to braze diamond and to investigate the effects of the belt speed of the tunnel furnace on the interfacial microstructure, residual stresses, and mechanical properties of brazed diamond. To obtain the desired results, the specimens were brazed at a certain temperature for three different belt speeds.

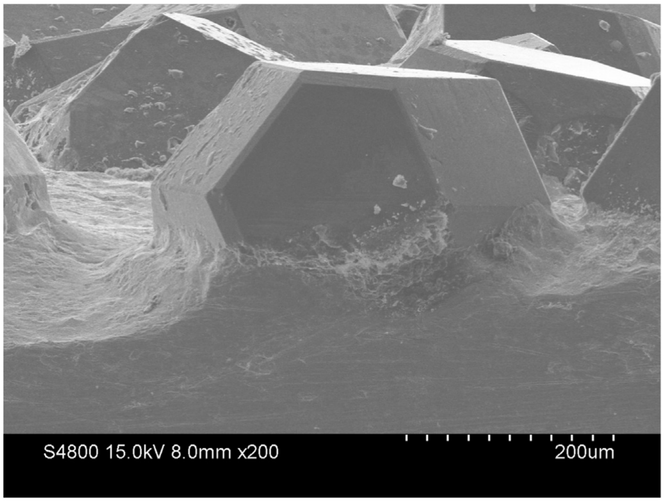

Fig. 4. The surface morphology of brazed diamond grits corresponding to the parameters 1080 °C/150 mm min^{-1}.

2. Experimental

2.1. Materials and brazing procedure

The specimen component utilized for this study consisted of the diamond abrasive grains, the active filler alloy, and the steel substrates. The dimensions of the grade HHD90 diamonds used in this study (Huanghe Whirlwind Co., Ltd., China) ranged from 300 to 350 μm. The filler alloy powder with added Cr to activate the brazing reaction and sieved by 300 mesh screen is displayed in Fig. 2. The composition of the filler alloy was 80Ni-9Cr-4Si-3B-3Fe-C (wt%). According to literature [13], the liquid phase temperature of the Ni—Cr filler alloy was 970 °C. The substrate was steel composed of 0.45% C with dimension of 20 × 10 × 5 mm in the normalization condition.

Prior to brazing, the oil contamination and impurities of the substrates from machining were cleaned through sand blasting and acetone. The filler alloy was evenly coated with a thickness of approximately 150 μm on the substrate surface. The diamonds were randomly distributed on the filler alloy, which led to the fabrication of the composite structure of the diamond grits/filler alloy/substrate.

The prepared composite bodies of the abrasive grain-filler alloy-substrate were placed on the mesh belt of the feeding zone of the tunnel furnace. Consequently, brazing could be performed in the mesh belt continuous tunnel furnace. The brazing temperature (1080 °C) and three different belt speeds (90, 120, and 150 mm min^{-1}) were selected. The cooling water pressure was 0.04 MPa and the protective gas flow entering the furnace was 6 $\text{m}^3\,\text{h}^{-1}$. The belt speeds of 90, 120, and 150 mm min^{-1} corresponded to the dwell durations of 13.7, 10.3, and 8.2 min; and cooling time of 55.6, 41.7, and 33.3 min, respectively, as