Int. Journal of Refractory Metals and Hard Materials 42 (2014) 23–29

Contents lists available at ScienceDirect

Int. Journal of Refractory Metals and Hard Materials

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

# The effects of solder alloys on the morphologies and mechanical properties of brazed diamond grits

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ARTICLE INFO

*Article history:*
Received 4 June 2013
Accepted 7 October 2013

*Keywords:*
Ag–Cu–Ti alloy
Ni–Cr alloy
Graphitization
Erosion
Microcracks
Mechanical properties

ABSTRACT

In this work, diamond grits are brazed with either Ag–Cu–Ti alloy or Ni–Cr alloy. Variations in the morphology of the brazed diamond grits, such as graphitization, erosion, microcracking and fracture, are observed. The compressive strength and thermal toughness index (TTI) of the brazed diamond grits are evaluated. The results obtained show that the morphologies of the original, unaltered diamond grits are similar to those of the brazed diamond grits. When the diamond grits were brazed using the Ag–Cu–Ti alloy, several disadvantageous phenomena, i.e., graphitization, erosion, microcracking, and fracture, were not observed, and the compressive strength and the TTI values of the brazed diamond grits were decreased only slightly. However, when the diamond grits were brazed with the Ni–Cr alloy, surface graphitization, erosion, microcracking, and fracture of the brazed diamond grits resulted, in addition to a significant reduction of the mechanical strength of the brazed diamond grits.



## 1. Introduction

Diamond is the hardest material known and is widely used in tool cutting, grinding, and polishing operations. Due to their low reactivity, diamond grits are also notoriously difficult to attach to tool matrixes. Generally, diamond grits are embedded in tool surfaces by electroplating, sintering, and other processes, which may present limitations when trying to achieve an adequate level of strength [1]. Recent works [2–6] reported the progress and use of active solder alloys based on alloys of Ag–Cu–Ti and Ni–Cr to bond diamond grits on tool surfaces, providing better performance in comparison with electroplating or sintering processes. The addition of active elements, such as Ti, Cr, or V, must be contributed to the solder alloy to enhance the interfacial adhesion strength and develop a preferred interfacial structure between the diamond grits and the bonding matrix [1,5–8]. Thus, Ni–Cr alloy and Ag–Cu–Ti alloy are commonly used as solder alloys [1,5,8]. When using these alloys, brazing operations are always carried out at temperatures of approximately 1000 °C to achieve the melting point of the solder alloys. This causes the diamond grits to undergo exposure to high temperatures during the brazing process. Graphitizing elements, such as the Ni contained in the brazing alloy, should induce the graphitization of diamond, although brazing operations are carried out in high vacuum or under protective atmosphere to prevent such occurrences. Furthermore, the stress distribution inside the brazing area exhibits localized high stresses at the brazing interface, resulting from differences in the thermal expansion coefficients of the diamond grits, brazing alloy and tool matrix. Therefore, the morphology and mechanical properties of diamond grits may be affected by high temperature, graphitizing and carbide elements and interfacial stress. This may result in the deterioration of tool performance, reducing the lifetime of the brazed diamond tool.

In early 1975, James T. Lowder and Edwin M. Tausch introduced nickel brazed diamond tools [9]. Subsequently, A. K. Chatopadhyay further developed the brazing technology of diamond grits [4]. Since this time, there has been ample research on the subject of diamond brazing to improve the performance of brazed diamond tools [10–13]. However, few details of the morphology and mechanical properties of diamond grits after brazing have been provided.

The objective of this study is to investigate the variations of the morphology and the mechanical properties of diamond grits brazed using Ag–Cu–Ti and Ni–Cr alloys. Accordingly, the graphitization, erosion pits, microcracking and fracture of brazed diamond grits are analyzed. Furthermore, the compressive strength and TTI values of diamond grits, as the most important values for the evaluation of the mechanical properties of diamond, are measured and compared.

## 2. Experimental procedures

To evaluate the effects of the factors mentioned above in the present investigation, a sample of diamond grits brazed with solder alloy is illustrated schematically in Fig. 1. Diamond grits with the size 40/45 mesh (355–425 μm) were used. The steel substrate was a commercial steel (AISI 1045), and the solder alloys used herein were powders of Ni–Cr alloy and Ag–Cu–Ti alloy. Prior to brazing, the surface of the steel substrate intended for brazing was polished mechanically and cleaned

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http://dx.doi.org/10.1016/j.ijrmhm.2013.10.003

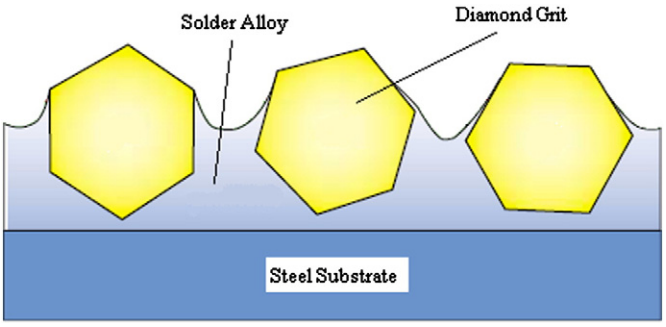


**Fig. 1.** A schematic illustration of the brazed diamond grits.

in an ultrasonic bath using acetone. Then, the solder alloy powder and the diamond grits were spread on the top of the steel substrate. Brazing operations were carried out in a vacuum furnace. The samples were brazed at 1050 °C for the Ni–Cr alloy and 920 °C for the Ag–Cu–Ti alloy. The dwell time was 5 min. The heating rate was at 10 °C/min. The system was maintained at a vacuum below $1 \times 10^{-2}$ Pa, and the specimens were furnace-cooled after brazing was completed. Subsequently, the samples were sectioned and polished for observation with cross-sectional micrography.

The solder alloys and carbides were removed from the brazed layer by electrolyzing the metal matrix from the specimen at 12 V in either dilute sulfuric acid (10 vol.%) for the Ni–Cr alloy or dilute nitric acid (10 vol.%) for the Ag–Cu–Ti alloy. Thus, only diamond grits with graphite on the surface were left behind. The microstructures of the diamond grit surfaces were examined by means of scanning electron microscopy (SEM) coupled with an energy dispersive X-ray (EDX) spectrometer (JEOL-840/EDAX). Additionally, the diamond grits were studied by Raman spectroscopy in the range from 1000 to 1700 $cm^{-1}$ using a Jobin Yvon HR800UV triple spectrometer with a CCD detector. The use of Raman spectra allows for characterization of the quality, in terms of the $sp^3$ and $sp^2$-hybridized carbon incorporated into the diamond grits, with both the influence of diamond grit size and the resonance Raman enhancement of the $sp^2$-carbon contributions taken into account [14]. The excitation laser was the 514.5 nm line of a Coherent Innova 70 Spectrum laser, which operated at a power of 5 mW using a 600 g/mm grating at the sample level. The size of the spot was approximately 0.01 mm with a displacement accuracy of 0.1 μm.

To further remove the graphite from the surface of the brazed diamond grits, the diamond grits with graphite were first placed in nitrohydrochloric acid, and the mixture was heated and boiled to remove the residual metal from the diamond grits. Next, the diamond grits, having been cleaned and dried, were fully mixed with sodium carbonate and heated to 500 °C. The mixture was preserved for 2 h at this temperature in the furnace. Lastly, the diamond grits were placed in perchloric acid and boiled. As a result, brazed diamond grits without graphite were attained [15].

Afterward, the compressive strength of the diamond grits was tested on a ZMC-II type diamond compressive strength tester and evaluated using a static method, in which diamond grits were placed between anvils and loaded in compression until failure occurred. At least 40 tests were performed for each diamond sample. Furthermore, the TTI value of the diamond grits was tested on the TI-03 friability index tester at different brazing temperatures. More specifically, the toughness index (TI) for a batch of diamond grains was determined by placing 2 carats of material in a capsule with a steel ball, agitating the material vigorously for a fixed amount of time (75 s.) and measuring the weight of the fragments produced at a certain size with respect to the starting weight of a certain size. The TTI was obtained by testing the strength of synthetic diamond that had been heated to 1100 °C. Measurement errors were estimated to be 5% at the probability of 95%.

## 3. Results and discussion

### 3.1. Morphological variation of the diamond grits

Profiles of diamond grits brazed with both solder alloys are shown in Fig. 2. These micrographs demonstrate that each brazed diamond grit is supported by the corresponding underlying solder alloy. Additionally, the attachment of the diamond grits is further reinforced by chemical bonding [16,17].

#### 3.1.1. Graphitization of the diamond grit surfaces

Images of original, unaltered diamond grits and brazed diamond grits whose solder alloys have been removed by the electrolyzing process are shown in Fig. 3. The unaltered diamond grits are presented in Fig. 3(a). The diamond grits brazed with Ag–Cu–Ti are shown in Fig. 3(b), and the diamond grits brazed with the Ni–Cr alloy are depicted in Fig. 3(c). It should be noted that there is no significant difference between the original diamond grits and the diamond grits brazed with Ag–Cu–Ti, except for a slight change in color. The color of the diamond grits brazed with Ag–Cu–Ti has a green tint, while that of the original diamond grits has a yellow hue. This is because the optical absorption of nitrogen tints the diamond grits with a characteristic yellow color. However, when diamond grits are brazed at high temperatures (920 °C or 1050 °C), a significant fraction of the single nitrogen atoms tends to aggregate, which gives rise to the green coloration of the diamond grits [18].

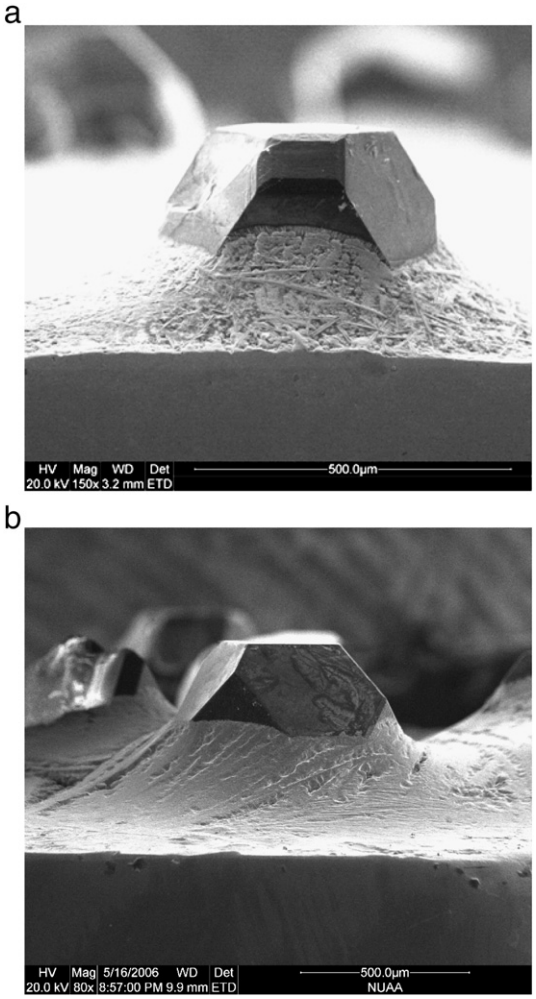


**Fig. 2.** Profiles of diamond grits brazed with the different solder alloys: (a) Profile with the Ni–Cr alloy; (b) Profile with the Ag–Cu–Ti alloy.