Effects of matrix characteristics on diamond composites

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A series of cobalt-matrix diamond composites was fabricated by hot pressing, and their microstructure, physical properties, transverse rupture strength and resulting fracture surface were studied in detail. Segments of the diamond composites were manufactured, and a one-segment circular sawblade was used for the evaluation of the sawing performance. Results show that the fracture surface of composites containing a cobalt matrix exhibits an excellent ductile appearance, while the fracture surface of composites containing an additive of tin powder in the cobalt matrix displays a less ductile behaviour due to the existence of a tin-rich brittle phase. It is also found that a diamond composite having low porosity, high hardness, and less surface attack of diamond particles will result in a low value of radial sawblade wear.

1. Introduction
Metal-bonded diamond composites have been widely used as drilling bits, sawblades and grinding wheels. Various techniques to fabricate these composites are available [1, 2]. They include cold pressing and sintering, hot pressing and infiltration. Selection of one of these manufacturing methods is based primarily on attaining the required physical properties of the metal bond without affecting the physical integrity of the diamond contained.

A number of metals such as cobalt, tungsten, nickel and iron, whose chemical affinity for carbon is high, are often used for bonding diamonds in tools. When diamond is heated in the presence of these metals, diamond integrity will be affected through surface attack during the manufacturing process. However, copper, tin and bronze metal powders, which have a poor chemical affinity for carbon, are also at times extensively used, since diamond is not affected significantly by these metals in the manufacturing process of composites. Depending on the specific applications required, the matrix behaviour can be varied by the addition of various alloying elements or alternatively by modifying the production conditions.

The wear-resistant diamond grains are held in a metallic bond. From the point of view of improving the tool’s cutting ability, a relatively brittle bond, e.g. the commonly used 80% Cu–20% Sn, will sometimes allow the diamonds to do the cutting, while a tougher bond, e.g. 90% Cu–10% Sn, has a tendency to glaze [2]. Generally speaking, the metal bond must be designed to wear at the same rate as the diamond grits so that when the diamond particles become worn, new grits will expose to facilitate constant efficient cutting [3].

In previous studies, Bronshtein et al. [4] studied the reaction of diamond with hard metals such as cobalt, tungsten and tungsten carbide. They stated that a successful composite tool design affords protection to diamond during the manufacture of a composite, and ensures the formation of a ductile cobalt bond around the diamond grains, which prolongs the useful life of tools operating under conditions of intense abrasive wear and heavy dynamic loads. However, few studies relating the nature of metal bonds to the properties of diamond composites have been reported.

In this paper, composites containing several cobalt-base bonds were fabricated into net shape using a hot-pressing method, and their microstructures and properties were studied. In addition, a circular sawblade with only one segment of diamond composites brazed to the rim of a steel core was manufactured. Sawing operations were carried out for evaluation of the sawing performance.

2. Experimental procedure
Five different bonds of diamond composites were fabricated for experimental studies. Table I gives the compositions of the original powders for the composites fabricated. Powders of each composite were blended for 1 h in a rotary mixer (α-shape). The mixed powders were hot-pressed in graphite moulds at 820 to 840 °C for 15 min under nitrogen gas and a mild pressure. Hot-pressed composites were cooled down to room temperature and then the pressure was released.

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Bond</th>
<th>Diamond size (μm)</th>
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<tbody>
<tr>
<td>A</td>
<td>100Co</td>
<td>95 5 300–425</td>
</tr>
<tr>
<td>B</td>
<td>95Co–5Sn</td>
<td>95 5 300–425</td>
</tr>
<tr>
<td>C</td>
<td>95Co–5Ni</td>
<td>95 5 300–425</td>
</tr>
<tr>
<td>D</td>
<td>95Co–5Ag</td>
<td>95 5 300–425</td>
</tr>
<tr>
<td>E</td>
<td>95Co–5W</td>
<td>95 5 300–425</td>
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</tbody>
</table>
relieved. The rectangular size of diamond composites fabricated was 40 cm × 7 cm × 10 cm.

Samples for microstructure studies were prepared by sectioning the composites by an electric discharge machine. These samples were abraded by a rotary diamond disc and then mirror-polished with diamond paste. The microstructure of the specimen was examined by an optical microscope or a scanning electron microscope (SEM).

The bulk density of the composites was measured by Archimedes' method, and the porosity of specimens was also estimated. The bond hardness of diamond composites was measured with a Rockwell B hardness tester using a standard B indenter. The measurements were taken at six points on the sides of the specimen ground by No. 1000 emery paper.

Transverse rupture strength (TRS) of the composites was measured by a three-point bending test. The resulting fracture surfaces from bending tests were examined by SEM for evaluation of the bond structure and diamond distribution. In addition, the extent of the diamond’s thermal damage was analysed.

Segments of the diamond composites were manufactured, and a circular sawblade with only one segment was used in the test. The workpiece material was Indian red granite. After sawing, the worn segment surface of the diamond composite was examined by SEM, and the radial sawblade wear was measured by a toolmaker’s microscope.

3. Results

The diamond composites produced were cut into a few sections, their structures were examined by SEM techniques and their physical, mechanical and sawing properties were determined.

3.1. Microstructure of the composites

Fig. 1a and b show typical SEM observations of the matrix of specimens B and D, respectively. Specimen B, which contains tin powder in the cobalt matrix, shows fewer pores. Clustering of tin-rich particles (white regions) is also observed. A larger amount of isolated pores was observed in specimen D with a silver–cobalt bond of the composite. Rounded pores indicate adequate sintering. Moreover, it can be seen that in both types of specimen, the boundaries between metal powders are not clearly outlined. Typical SEM photomicrographs of the diamond–matrix interface of specimens B and D are given in Fig. 2a and b.