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EXTREME HARDNESS ACHIEVEMENTS IN BINDERLESS CUBIC BORON NITIDE TOOLS

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Introduction

Cubic boron nitride (cBN) in polycrystalline arrangement is a high-performance tool material in metal cutting industries for precision cutting and finishing of hardened alloy steels, titanium alloys, high-strength nickel superalloys and powder metal alloys. Despite polycrystalline diamond's (PCD) superior edge over cBN on mechanical properties, the chemical inertness and thermal stability of cBN at high temperatures made it highly preferable particularly for machining hard alloys. Therefore, research is needed to further enhance the mechanical properties of cBN. Such developments would make these superhard materials meet the stringent requirements of new applications and enhance their performance in established areas as well.

There are two types of binderless cBN tool: one is a pure cBN and the other is a wurtzite/cubic boron nitride (wBN/cBN) composite. Wurtzite boron nitride (wBN) is a hard phase similar to cBN. The cost of production of wBN/cBN is much lower than that of traditional cBN because the starting wBN powders can be produced in large quantities inexpensively by shock loading graphitic form of BN. Although binderless cBN and wBN/cBN are very efficient in the finishing processes of milling and turning of hardened steels and titanium alloys, their hardness (40-50 GPa) is still well below that of PCD (65-80 GPa). Consequently a preliminary study of a novel laser/waterjet heat treatment was conducted to find that the hardness of the wBN/cBN composite could reach the hardness of PCD [1]. The new discovery of rapidly quenched wBN/cBN composite matching the hardness of PCD can have vast implications in the tooling industry. Hence, in this paper, we made a detailed study of laser heat treated single phase cBN and dual phase wBN/cBN tools in order to identify the fundamental phase transition and microstructure refinement features that contribute to the hardness improvements.

Experiment

In this work, a novel laser heat treatment process (Fig.1) was performed using a continuous wave CO_2 laser beam of 1 mm spot size and a speed of 68 mm/s. A low laser power of 200 W was used to prevent melting, scribing or cutting of boron nitride. The laser beam was immediately followed by waterjet stream of 400 kPa with a distance of 3.4 mm from the laser beam. Also, the laser beam was surrounded by a stream of air to prevent the laser-water interaction. The laser/waterjet (LWJ) system is described in [2].

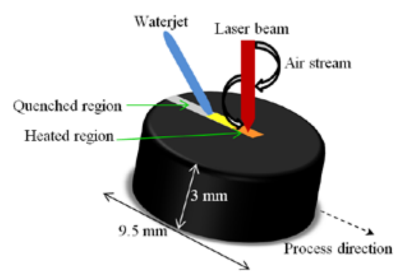

Fig.1 Schematic of LWJ heat treatment process.

Characterization

Indentation hardness tests were performed using a Vicker's diamond pyramid indenter. Measurements were made on the length of the diagonals of the indentations using a high resolution optical microscope and optical profilometer. A number of hardness measurements (10 to 20) were made to ensure the reliability of test data.

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General microstructure analysis of initial (untreated) sample was done on HRSEM in high current mode which resolves most of the problems with sample charging but affects the resolution.

Results

Visual examination of laser heat treated samples revealed a color change from light-absorbing black/gray to transparent white. Such an effect is ascribed to a change in crystal morphology following Sachdev's classification of the crystalline morphology of cBN according to color, size and transparency [3]. Figure 2 shows a statistical boxplot comparison between the results of hardness tests of single phase cBN after 50 laser passes (the maximum increase in hardness for the single phase cBN) and dual phase wBN/cBN after one pass. The laser treatment of the dual phase wBN/cBN has almost doubled the hardness and matched with that of PCD. It appears that the effect of heat treatment is more pronounced in wBN/cBN compared with single phase cBN. The average hardness was increased by 100% in wBN/cBN for a single pass and 20% in single phase cBN for 50 passes.

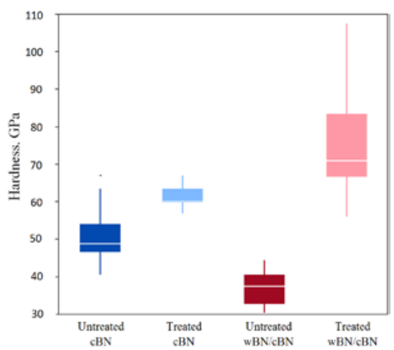

Fig.2 Vicker's indentation hardness test data of single phase cBN (50 laser passes), and dual phase wBN/cBN (single laser pass).

HRSEM analysis of the microstructure has revealed formation of nano-sized grains and significant cracking and fracture of wBN lamellas during laser heat treatment. Figure 3 and 4 shows the microstructure of the material before and after treatment respectively.

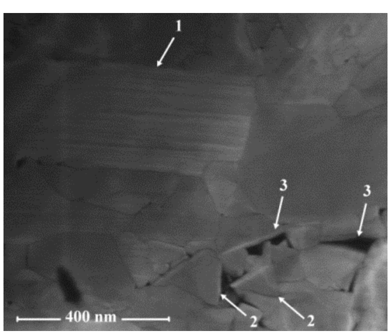

Fig.3 Detailed microstructure of untreated wBN/cBN composite: (1) Micro-band sub-structure of the lamellas; (2) Polyhedral grains at the fragmentation interfaces; (3) Pores due to polyhedral faceting.

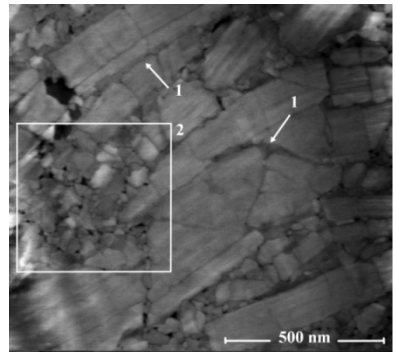

Fig.4 Type III of the heat treated microstructure: (1) Interlayer at grain boundaries; (2) Large of nano-sized grains of rounded shape.

Conclusion

The laser-waterjet heat treatment increased the hardness of binderless cBN sample by 20% (nominal 60 GPa) while it increased the hardness of binderless cBN/wBN sample by 100% (nominal 75 GPa) reaching the hardness of polycrystalline diamond (65-80 GPa). The binderless dual phase is more affected by the treatment process and the treatment is only affecting the surface layer. A number of characterization techniques including Raman, HRSEM, and XRD analysis were used to identify the mechanisms responsible for the increase in hardness. A combination of amorphous phase formation at the grain boundaries and nano-sized grain formation are suggested as the mechanisms responsible for the increased hardness.

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3