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The effect of tungsten buffer layer on the stability of diamond with tungsten carbide–cobalt nanocomposite powder during spark plasma sintering

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Abstract

WC–Co nanocomposite powder produced by spray pyrolysis–continuous reduction and carbonization technology, diamond coated with tungsten (W) by vacuum vapor deposition and uncoated diamond were used in this study. This work adopted the spark plasma sintering (SPS) process to prepare diamond-enhanced ultrafine WC–Co cemented carbide composite material. The effects of W buffer on the stability of diamond with WC–Co nanocomposite powder during SPS were investigated. Results showed that the uncoated diamond was mechanically embedded in WC–Co cemented carbide matrix, while the diamond coated with tungsten was combined chemically with WC–Co cemented carbide matrix. Moreover, there was a transitional layer between the diamond and the matrix which could improve the thermal stability of the diamond, prevent carbon atom of the diamond from dissolving in Co phase and increase the bonding strength of the interface between the diamond and the matrix.

Keywords: Diamond; WC–Co nanocomposite powder; Cemented carbide; Spark plasma sintering (SPS)

1. Introduction

Nowadays there are mainly two kinds of tools used to cut hard rocks, one is tungsten carbide tool and the other is diamond tool. The former has good toughness against impact and low abrasive resistance, while the latter has high abrasive resistance and bad toughness against impact. Neither performs well. Therefore it is necessary to develop a new kind of tool with the performance combining the advantages of the two above, which could be widely used in the future. Great efforts have been made in the field for years in America and Japan [1–5].

The ultrafine WC–Co cemented carbide has better performance than that of WC grains over 1 μm. It is widely applied in many fields because of its excellent properties, such as miniature drills for highly integrated printed circuit boards (PCBs), pins for dot-printers, wood machining, dental work and wear parts [6–8].

Cemented carbide is commonly consolidated with the temperature from 1350 to 1450 °C, which is too high for a diamond that it will be thermally eroded seriously; as a result, the properties of a diamond-enhanced cemented carbide composite are very weak. In order to improve the mechanical properties of a diamond-enhanced cemented carbide composite, the sintering temperature should be lower. Although activated sintering could decrease the sintering temperature, the addition of phosphor and nickel will deteriorate the toughness against impact and the abrasion resistance of the composite simultaneously [9].

Spark plasma sintering (SPS) is fundamentally different from conventional heating. SPS enables a powder compact to be sintered by Joule heat and spark plasma generated by a high-pulsed electric current through the compact. It is an effective heating method without significant thermal energy losses. Some of its advantages include energy saving, rapid heating rates, temperature reducing, fine microstructure obtaining and hence improved mechanical properties [10–14]. The SPS technique makes it possible to prepare diamond-enhanced WC–Co cemented carbide composite button that combines high abrasion resistance and hardness of diamond with high toughness against impact of ultrafine cemented carbide ideally with shorter time and lower temperature.

Titanium (Ti) is conventionally used as a buffer layer on diamond [5], however, the study of tungsten used as a buffer

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layer on diamond is seldom touched [1]. The differences between the chemical bonding strength of W buffer layer and Ti buffer layer are not very clear. The tungsten film can be carbonized into WC film by the carbon atom in the surface of the diamond, which is wet by cobalt phase easily in the matrix during liquid sintering process. The interface energy between the matrix and the diamond will be lowered, therefore the bonding strength of the interface between the coated diamond and the matrix will be improved. In this work, an investigation was carried out to study the effect of tungsten buffer layer on the stability of diamond with WC–Co nanocomposite powder during spark plasma sintering.

2. Experimental

WC–10Co nanocomposite powder produced by spray pyrolysis–continuous reduction and carbonization technology, diamond coated with tungsten by vacuum vapor deposition and uncoated diamond were used in this study. The size of the diamond is from 0.150 to 0.375 mm. The WC–Co nanocomposite powder was ball-milled in acetone for 48 h. After milling, it was dried at 90 °C in a vacuum oven. The diamond-enhanced ultrafine WC–Co cemented carbide composite material was consolidated by spark plasma sintering process for 3 min at 1000, 1100 and 1280 °C, respectively, under a pressure of 30 MPa. The schematics of D.R.Sinter® SPS3.20 SPS system produced by Sumitomo Coal Mining Co. Ltd was shown in Fig. 1.

In order to improve the thermal stability of the diamond and the bonding strength of the interface between the

Table 1
Composition of WC–10Co nanocomposite powder

Total carbon content (wt.%)	Free carbon content (wt.%)	Oxygen content (wt.%)	Surface area (m^2 g^1)	Co content (wt.%)	VC/Cr_3C_2 content (wt.%)
5.49	0.16	0.20	11.7800	10.05	0.40/0.40

diamond and cemented carbide, the method of coating tungsten on the surface of the diamond by vacuum vapor deposition was adopted. The coated diamond was characterized for phases by X-ray diffraction (XRD) and for microstructure by a scanning electron microscopy (SEM); the starting WC–Co powder was characterized for phases by XRD, for morphology and particle size by an atomic force microscopy (AFM) (Digital Instruments NanoScopeIV, VEECO company, USA) (tapping mode). And the particle size of WC–Co nanocomposite powder was also characterized by a BET analyzer.

Sintered specimens with diameter of 30.5 mm and height of 6.0 mm were characterized for interface microstructure between the diamond and the matrix by SEM. The phases were characterized by XRD and Laser Confocal Raman Microscopy. A He–Ne laser excited at 632.8 nm was used with a power density of 4.7 mW and a spot diameter of 1 μm. The density was determined by Archimedes' principle. The transverse rupture strength (TRS) of specimens was measured after the following process. The specimens were sawed with a size of 20 × 6.5 × 5.25 mm^3 by electrical discharge machining. Their surfaces were polished mechanically with emery papers down

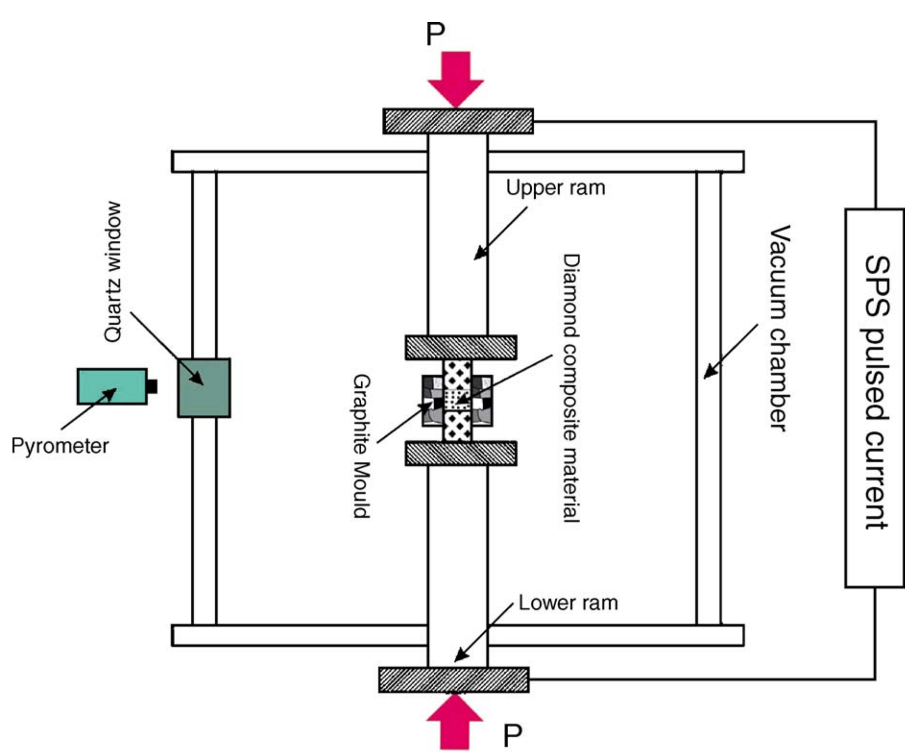

Fig. 1. Schematics of spark plasma sintering (SPS) system used for the consolidation of diamond-enhanced ultrafine cemented carbide composite material.