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Preparation and performance of chemical vapor deposition diamond coatings synthesized onto the cemented carbide micro-end mills with a SiC interlayer

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ABSTRACT

In this paper, bi-layer (SiC + diamond) coatings were synthesized on 0.8-mm-diameter cemented carbide micro-end mills. The influences of SiC interlayers and diamond coatings on the morphologies, phase composition and fracture strength were investigated. The cutting performance of the bi-layer (SiC + diamond) coated tools was validated by dry cutting of aluminum alloys. The results indicated that the binder Co reacted with SiC to form cobalt silicides (i.e., Co_2Si and CoSi), suggesting that the SiC interlayer suppressed the deleterious effects of Co, successfully. Neither the presence of the SiC interlayer nor the bi-layer coatings reduced the fracture resistance of the tools. The workpieces had a better surface finish after being cut by the coated tools than those cut by the uncoated tools. This result indicated that the bi-layer (SiC + diamond) coated tools exhibited better cutting performance than the uncoated tools. Thus, SiC interlayers were demonstrated as a suitable option for adherent diamond coatings on the cemented carbide components and cutting tools.

1. Introduction

Chemical vapor deposition (CVD) diamond coated cemented carbides (WC–Co) possess extreme hardness and inertness, high wear resistance and low friction, leading to the prolonged life of the cutting tools [1,2]. However, the CVD diamond coated tools exhibit several limitations regarding the poor adhesion of the diamond coatings. It has been generally determined that the major reason for the poor adhesion is the strong catalytic effect of the binder phase cobalt (Co) in the substrates. The Co binder will preferentially suppress diamond growth and promote the formation of a graphitic intermediate layer [3–5].

To solve this problem, researchers have studied this adhesion issue for several decades and developed several approaches. These approaches are primarily categorized into two types: the removal of cobalt from the substrate surface using chemical pretreatments [6] and the introduction of an intermediate layer between the diamond coating and the substrate [7]. Although the former approach can eliminate partially the deleterious effects of Co, it results in a decrease of the toughness and embrittlement of the WC–Co substrates [3,8]. Thus, this approach cannot be employed for some special mechanical parts, e.g. micro-end mills. Alternatively, the latter approach suppresses the deleterious effects of Co by using an interlayer for enhancing the adhesion [9].

Among the interlayer materials, the effectiveness of cubic silicon carbide (β-SiC), particularly as an interlayer, has been recently confirmed [9]. The β-SiC interlayer is expected to reduce the thermal stress in the coating, which caused by the coefficient of thermal expansion (CTE) mismatch between the diamond and the substrates [10]. In addition, SiC will react with Co to form carbon and cobalt silicides, which do not affect the diamond deposition process and deteriorate the adhesion of diamond coatings [11–13]. Tao Wang et al. [14] synthesized Diamond/β-SiC/cobalt silicide composite coatings on cemented carbide inserts using hot filament chemical vapor deposition. In their investigation, the effectiveness of these interlayers in improving the adhesion of diamond coatings was confirmed by Rockwell C indentation tests. However, the interlayers prepared by Tao Wang [14] and coworkers were deposited after the two-step chemical pretreatment process of the Murakami solution and the acid solution, and the consequent reduction of its breaking strength prior to diamond CVD. In our prior studies [15], SiC interlayers were synthesized without chemical pretreatments, and the effectiveness of the interlayers on improving the diamond coatings has already been demonstrated. However, to date, only scarce information concerning the performance of the tools with bi-layer (SiC + diamond) coating is available in the literature.

In the present work, SiC interlayers were pre-produced on cemented carbide micro-end mills, and diamond coatings were subsequently

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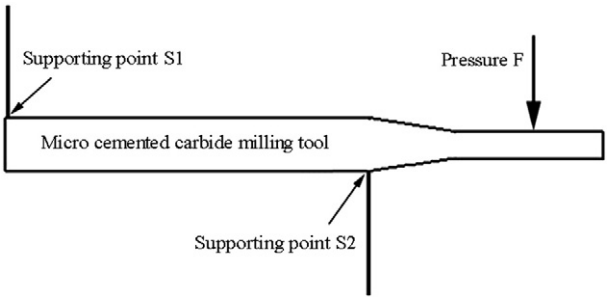

Fig. 1. Schematic of the testing rig for measuring the fracture resistance of the tools.

deposited onto the tools with the SiC interlayer. The morphology, phase composition and breaking strength of the tools with the SiC interlayer and the tools with the bi-layer (SiC + diamond) coating were observed. Furthermore, the cutting performance of the tools with the bi-layer coatings was validated via a cutting test. We compared our findings with the results obtained from the commercial WC–Co end mills.

2. Experimental details

2.1. Preparation of the SiC interlayer and the diamond coating

Commercial cemented carbide–6 wt.% cobalt (WC–6%Co) end mills with a diameter of 0.8 mm and a grain size of approximately 1.0 μm were used as the substrates for depositions. The deposition of SiC interlayer and the subsequent growth of diamond coatings were performed using the same high current extended direct current (DC) arc plasma CVD apparatus, which has described in earlier works [16].

SiC depositions were performed on the tools previously pretreated for removing the oxide films, and the grinding traces were formed by finish machining. Due to the complex surface of the tools, the traditional grinding pretreatment using diamond powder was not applicable. The tools were ultrasonically pretreated for 30 min with a 4-μm diamond powder suspension. Next, the tools were cleaned with ethanol in an ultrasonic bath. A gas mixture of argon (Ar, purity of 99.99%), hydrogen (H_2, purity of 99.999%) and tetramethylsilane (TMS, purity of 99.9%) was chosen as precursor for the SiC deposition. The total pressure was maintained at 0.5 kPa, as measured by a piezoresistive diaphragm manometer. The flow rates of Ar, H_2 and TMS were 1800 sccm (standard cm^3 min^{-1}), 100 sccm and 5 sccm, respectively. The substrate temperature was 1123 K ± 10 K, which was monitored by an optical pyrometer. After three hour deposition, a continuous SiC interlayer was formed onto the substrate surface.

Prior to diamond deposition, the tools were ultrasonically seeded for 60 min with a 0.5-μm diamond powder alcohol suspension (concentration: 50 ct/l). The diamond coatings were deposited onto the tools using the same CVD apparatus; the parameters used were as follows: a gas mixture of Ar, H_2 and methane (CH_4, purity of 99.995%) was used as precursor for the diamond deposition. The flow rates of Ar, H_2 and CH_4 were 1800 sccm, 100 sccm and 10 sccm, respectively. The chamber pressure was maintained at 0.5 kPa, the deposition temperature was approximately 1173 K, and the deposition time was set at 6 h. The nanocrystalline diamond coatings were prepared onto the substrates with the SiC interlayer under these deposition conditions.

2.2. Characterization and performance

A field emission scanning electron microscope (FESEM, ZEISS Auriga Focus Ion Beam/Field-Emission Scanning Electron Microscope dual-cross system) was used to characterize the surface and cross-sectional morphologies of the tools with the SiC interlayer and the tools with the bi-layer (SiC + diamond) coating, and an energy dispersive X-ray spectrometer (EDS) was utilized to perform microanalysis of the selected areas of the tools.

Both the tools with the SiC interlayer and the bi-layer coating were analyzed using an X-ray diffraction (XRD, Bruker D8 Advance) apparatus at a grazing angle of 2° (scan step size: 0.02°). The bonding structure of the diamond coatings was determined using a Raman spectrometer (Renishaw RM2000) at an Ar^+ laser wavelength of 514.5 nm and a laser power of 100 mW.

To evaluate the mechanical properties of the tools, a simple testing rig was designed to use. Fig. 1 depicts the schematic of the testing rig in which a tool would be supported on two points (the ends of the tool holder, S1 and S2), and a load F was applied just on the middle part of the cutting position. The critical load F_c, to fracture the tool,

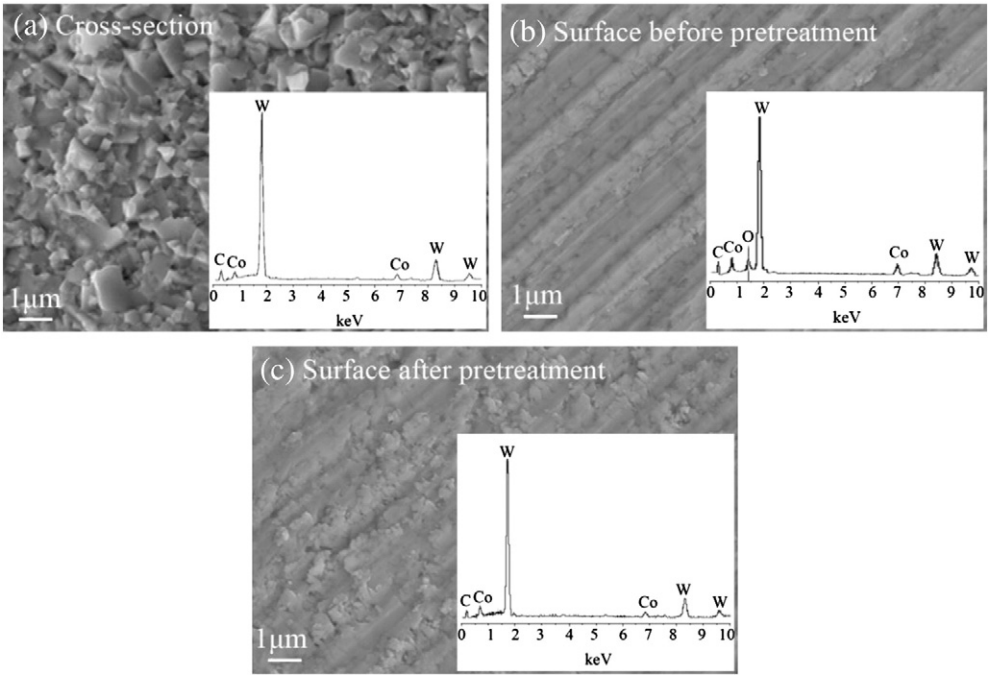

Fig. 2. FESEM micrographs and EDS spectrum of the tools: (a) the cross-section, (b) the surface before the ultrasonic pretreatment and (c) the surface after the ultrasonic pretreatment.