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Sequential morphology of cobalt from cemented tungsten carbide in microcrystalline and nanocrystalline diamond films by HF-CVD

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ABSTRACT

Polycrystalline diamond films are used as protective films on cutting tools for carbon fibre-reinforced plastic, aluminium alloy or graphite because of their excellent hardness and high thermal conductivity. As a base material for tools, cemented tungsten carbide with a Co binder (WC-Co) is usually employed. However, the Co binder in the WC substrate causes the non-uniform formation of diamond films. Herein, the mechanism of non-uniform film formation during diamond deposition on WC-Co substrates using hot filament chemical vapor deposition (HF-CVD) method was investigated. The surface and cross-section of the substrates were observed at each process, from substrate preparation to the formation of the microcrystalline and nanocrystalline diamond (MCD and NCD, respectively) films. During the filament carburization process before diamond film deposition, Co particles were segregated on the substrate surface, and some WC grains were uplifted from the substrate surface. In the formation of MCD films, non-uniform diamond films were formed because of the Co particles remaining on the film surface, as reported in previous studies. Meanwhile, non-uniform NCD films were formed because of uplift of the WC grains on the substrate surface caused by the generation of the carbon filament extending from the Co particle to the substrate. In addition, the Co particles were covered with a carbon shell. In the deposition of MCD and NCD films, the Co binder segregated to the substrate surface before diamond nucleation. Owing to the negative effect of Co, the segregation of Co in the initial stage should be prevented to form a good-quality uniform film.

1. Introduction

Diamond films are used as protective films because of their excellent wear resistance due to high hardness (∼145 GPa) [1,2] and excellent adhesion due to high chemical stability or high thermal conductivity [3–5]. In particular, diamond-coated tools are widely used in industry as cutting tools for difficult-to-machine materials such as CFRP, aluminium alloy, or graphite [6–8]. In general, cemented tungsten carbide (WC) is used as the base metal of these diamond-coated tools. Cemented tungsten carbide is composed of sintered WC grains with a Co binder, which is denoted by WC-Co. WC-Co exhibits excellent hardness and toughness [9].

Chemical vapor deposition (CVD) [10,11], particularly hot-filament CVD (HF-CVD) method, is widely used to deposit polycrystalline diamond films on cutting tools. In the HF-CVD method, a hydrocarbon gas is decomposed using a high-temperature metal filament heated at approximately 2200 °C, and diamond is deposited on the substrate [12]. This method is widely employed in the industry because of its simple equipment configuration, wide deposition range, and ability to deposit films on complex shapes. Polycrystalline diamond films are classified as microcrystalline and nanocrystalline diamonds (MCD and NCD, respectively), which have crystal sizes of several micrometres and less than 100 nm, respectively. MCD exhibits good crystallinity and excellent wear resistance and adhesion; however, its large surface roughness reduces the machining accuracy of the tools. By contrast, NCD has excellent tribological properties owing to its low surface roughness, but its ball shape causes easy wear and poor adhesion [13]. Evidently, NCD and MCD have complementary properties [14,15].

WC-Co is one of the best materials for tools; however, when diamond films are directly deposited on the WC-Co substrate by CVD, Co inhibits

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