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Preparation and cutting performance of ultra-smooth CVD composite diamond coated ladder-shape drilling tools

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ABSTRACT

The preparation of ultra-smooth composite diamond (USCD) coated ladder-shape drilling tools is studied. These are produced by growing microcrystalline diamond (MCD) and nanocrystalline diamond (NCD) layers employing the hot filament chemical vapor deposition (HFCVD) method on WC-Co parts. A double hot-wire arrangement apparatus is adopted, the complex shape tool is placed between upper tantalum wires and lower tantalum wires so that all parts of the tool can be coated with diamond. The drilling experiments are conducted for assessing the cutting performances of the MCD and USCD coated tools using carbon fiber reinforced plastics (CFRP) as the workpiece, the uncoated tool is also used in the drilling experiments for the sake of contrast. The results show that the MCD and USCD coated tools exhibit a better cutting performance than the uncoated one, besides, the USCD coated tool displays the best wear resistant. The workpiece is precisely machined with a smooth and bright surface by the USCD coated tool, and there are no defects such as crackle and burrs in the hole exit, the durability of the USCD coated tool and the processing quality of the workpiece have been greatly improved.

1. Introduction

CFRP have been widely used in military, aviation and racing fields due to the remarkable properties such as low thermal expansion coefficient, high specific strength and high corrosion resistant, meanwhile, CFRP are considered as a kind of difficult-to-machine material because of their high hardness and inhomogeneous nature [1–4]. In the process of machining CFRP laminates using common cemented carbide drill, the tool is severely worn out because of the abrasive nature of the carbon fibers, regarding the quality of machined workpiece, there are lots of defects such as fiber pullout and breakage, piles delamination and exit burrs [5–8].

The HFCVD (hot filament chemical vapor deposition) method is favored by a majority of researchers among various CVD methods due to the advantages such as simple structure, low cost, easily-controlled process parameters, moreover, it is very suitable for the deposition of complex structure tools [9–12]. The diamond film deposited by the method of HFCVD has excellent properties including high elastic modulus, favorable wear resistance, high thermal conductivity, extremely high hardness, low frictional coefficient and low thermal expansion coefficient [13–16]. Many outstanding properties of diamond film have shown great prospect as a protective coating for cutting tools in many fields, which not only could enhance the wear resistance and prolong the tool life of the coated tool, but also improve the quality of the machined workpiece significantly during the machining process. There is a huge advantage in cutting titanium alloy, aluminum base alloy and composite materials using CVD diamond tools [17].

Based on the fact that common cemented carbide drills wear seriously when processing some difficult cutting materials such as CFRP, a new-type ladder-shape drilling tool with a complex structure which is used to process automotive brake pads is adopted as the cutting tool. A lot of literature shows that the frictional coefficient of diamond films on WC-Co substrate surface plays an important role in improving cutting performance of the tool, thus, further efforts on reducing friction coefficient of diamond films are essential. In addition, little study on ultra-smooth composite diamond (USCD) film deposited onto carbide ladder-shape drilling tool with complex structure has been reported. We find that the USCD film on carbide ladder-shape drilling tool can reduce friction coefficient effectively in our study. The machining quality and process efficiency will be improved substantially in the process of machining the workpiece with this kind of tool in the automobile industry.

In the present work, MCD and USCD coated ladder-shape drilling tools are fabricated by synthesizing different diamond films on WC-Co substrates. A double hot-wire arrangement apparatus which is a diamond film preparation device for complex shape tool is proposed. During the fabrication for USCD coated tool, a layer of microcrystalline

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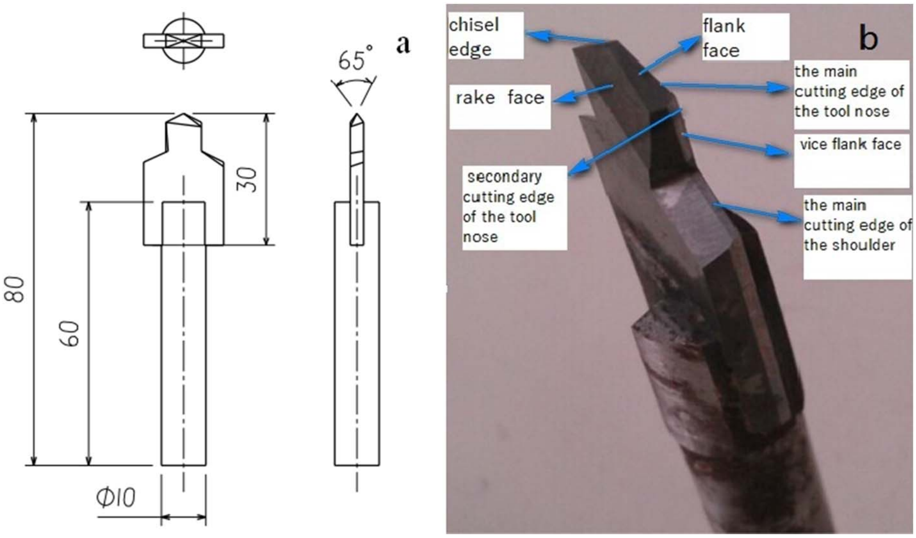

Fig. 1. Schematic diagram of the cutting tool: (a) tool dimensions, (b) cutter structure.

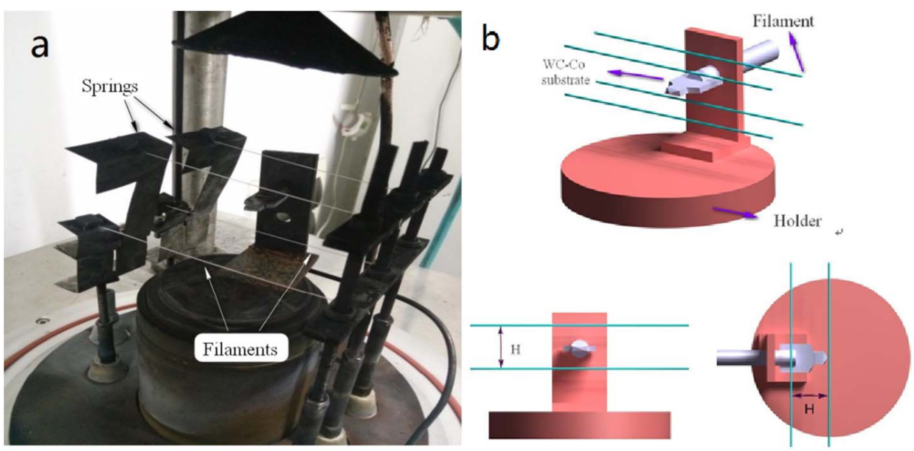

Fig. 2. Double hot-wire arrangement apparatus: (a) Physical map, (b) Schematic diagram.

Table 1
Deposition parameters for composite diamond film.

	Nucleation period	Growth period I (for depositing MCD film)	Growth period II (for depositing NCD film)
Acetone/H_2/Ar flow (mL/min^{-1})	60/200/0	50/200/0	50/250/250
Reaction pressure (KPa)	1.8	3.3	1.8
Bias current (A)	3	2.0	2.0
Deposition time (h)	0.5	5	7

diamond (MCD) film is coated on WC-Co substrate first, and then a layer of nanocrystalline diamond (NCD) film is covered on the microcrystalline diamond (MCD) film [18]. The cutting performances and the qualities of the machined workpieces for the uncoated and the two types of coated tools are compared and analyzed. Scanning electron microscopy (SEM, JSM-6390LV) is applied to elucidate the surface and cross-sectional morphologies of as-fabricated diamond films and examine the worn morphology of the tools. Raman spectroscopy is used to assess the quality of as-deposited MCD and USCD films. Furthermore, cutting performances of the diamond coated tools and the uncoated tool are investigated by drilling experiments, there are no lubricants in the drilling processes, the hole quality is investigated using tool microscope (VHX-2000).

2. Experimental details

The USCD film with a layer of MCD film and a layer of NCD film on WC-Co substrate surface was deposited by the method of HFCVD. Specially designed carbide YG6 ladder-shape tool (WC-6%Co) with dimensions of Φ10 mm × 80 mm was used as the substrate, as shown in Fig. 1. Precede to the deposition process, the WC-Co substrate was pretreated by a two-step chemical etching procedure. Firstly, the WC-Co substrate was immersed in the Murakami's solution (10 g $K_3[Fe(CN)]_6$ + 10 g KOH + 100 mL H_2O) in an ultrasonic vessel for 30 min to attack WC grains and roughen the substrate surface, and then in order to reduce the surface cobalt concentration, the WC-Co substrate was dipped in H_2SO_4 (30%) + H_2O_2 (70%) for 20 s. Finally, the substrate was ground for 60 min with 1 μm diamond powder suspension followed by ultrasonically cleaning in ethanol for 10 min. The composite diamond film was synthesized in a bias-enhanced HFCVD chamber, the reaction gases were hydrogen gas (H_2), argon gas (Ar) and acetone gas (CH_3COCH_3), a bias voltage was applied to promote the formation of atomic hydrogen and carbon radicals effectively.

In order to deposit diamond film on complex shape tool, an apparatus of double hot-wire arrangement was adopted with aim to get uniform temperature field distribution on the substrate surface. Fig. 2a showed that four tantalum wires with a diameter of 0.6 mm were utilized as hot filaments which were dragged to be straight by fixed springs in parallel and equidistance manner, the complex shape tool was placed in the middle of the filaments. The filament temperature was detected with an infrared thermometer while the substrate