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Review

Diamond deposition on hardmetal substrates – Comparison of substrate pre-treatments and industrial applications

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ABSTRACT

Diamond deposition on various hardmetal tools is widely used. For applications where the mechanical forces are low diamond coatings have long lifetimes, but especially for heavy duty applications the reproducibility of the diamond coating adhesion is not adequate.

Wear and lifetime of diamond coated tools are determined by the diamond microstructure, the coating thickness, and the adhesion of the coating.

The diamond substrate interface is important for layer adhesion, but in the case of diamond deposition on hardmetal tools, the interface can change during the diamond deposition. For this reason, surface pre-treatments are important, not only for a better diamond nucleation, but also to create a stable interface that allows good coating adhesion.

The various aspects of different surface pre-treatments of hardmetal tools will be discussed.

Contents

1. Introduction

CVD-diamond deposition has been available since 1982 [1] and because of diamond's high hardness and wear resistance, tool applications were immediately investigated [2]. Diamond

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deposition on hardmetal substrates started early because hardmetal tools and hard coatings were already well-established [3,4].

During the first investigations of diamond deposition on hardmetal substrates, it became obvious that Co contained in the binder phase is detrimental to the chemical vapor deposition of diamond [5,6]. Pre-treatment procedures are usually aimed at depleting the Co content at the hardmetal substrate surface by selective chemical etching [7]. Another method to immobilize the Co binder is to produce stable cobalt compounds, such as borides and silicides, which are quite stable under diamond deposition conditions [8]. The application of thin-intermediate layers is also a promising technique for the deposition of well adherent diamond films [9].

For the industrial applications of diamond coatings it was also necessary to optimize the growth parameters, diamond microstructure, and homogeneity of the depositions [10].

Today, CVD-diamond coatings can significantly prolong the lifetime of tools used in cutting and milling of non-ferrous materials, such as Al(Si) alloys, graphite, and plastics [11].

2. Wear and failure of diamond coatings

Wear of the diamond coatings is caused by mechanical and chemical reactions reasons.

- Chemical wear – reaction between work piece and diamond.
- Mechanical wear of the coating – crystallographic breakage of larger diamond crystals.
- Mechanical wear of the interface – the coating peels of due to a weak interface bonding and mechanical stress.

An other point of view is to consider the forces acting during the application.

- High forces – if the substrate–diamond interface is insufficient the layer peels off. Substrate roughness, pre-treatments, and substrates mechanical properties are important.
- Medium forces – increased surface reactions and crystallographic breakage of diamond crystals. Diamond microstructure, layer texture, layer thickness are relevant.
- Small forces – high hardness and low friction of diamond determines the wear. Surface roughness, work piece composition, machining parameters are important.

Due to the different forces present during the various tooling operations, and the various wear mechanism caused by different work pieces, it is necessary to optimize diamond coated cutting tools. This optimization can be done only by an in-depth understanding of substrate geometry, nature of the interface and properties of the coating.

3. Diamond surface roughness and microstructure regulated by diamond deposition

During the CVD reaction, diamond crystallizes directly from the gas phase. To initiate nucleation, reactive carbon species such as radicals or ions and atomic hydrogen ($H^\cdot$) have to be produced and brought to the substrate surface. Atomic hydrogen is also needed to remove graphite and stabilizes sp^3-carbon at the diamond surface [12,13].

The reactive gases are usually prepared by thermal or plasma decomposition (e.g. hot-filament, microwave or DC-plasma and various plasma jets) [14–17]. For diamond deposition on hardmetal tools the hot-filament and Balzers DC-arc [18] are mostly used.

The surface roughness and grain size in the diamond layer are important consideration for wear and crystallographic breakage. To vary the diamond layer properties the deposition conditions have to be controlled. The ratio between atomic hydrogen and carbon is most important for the diamond quality. If the $H^\cdot/C$ ratio is high, well facetted diamond crystals with less defects are grown ((1 1 1)-facets). With decreasing $H^\cdot/C$ ratio the morphology change to (1 0 0)-facets, ballas and ballas-graphite deposition (Fig. 1) [19]. The microstructure of ballas-diamond is characterized by many defects like twin-grain boundaries and additional grain boundaries. The single-crystalline grains of ballas-diamond are in the range of 20 nm [20].

In addition to ballas-diamond, nano-crystalline (NCD) and ultra-nano-crystalline diamond (UNCD) are described. These types of coatings are produced by special deposition conditions forcing secondary nucleation. Compared to ballas diamond the microstructure of NCD and UNCD contains more grain boundaries and less twin-grain boundaries and a medium grain size of 5 nm [21].

As described above, a great variety of diamond microstructures can be grown by varying the deposition conditions but it should be noted that these changes also consequently effect deposition parameters like layer growth rate and surface roughness.

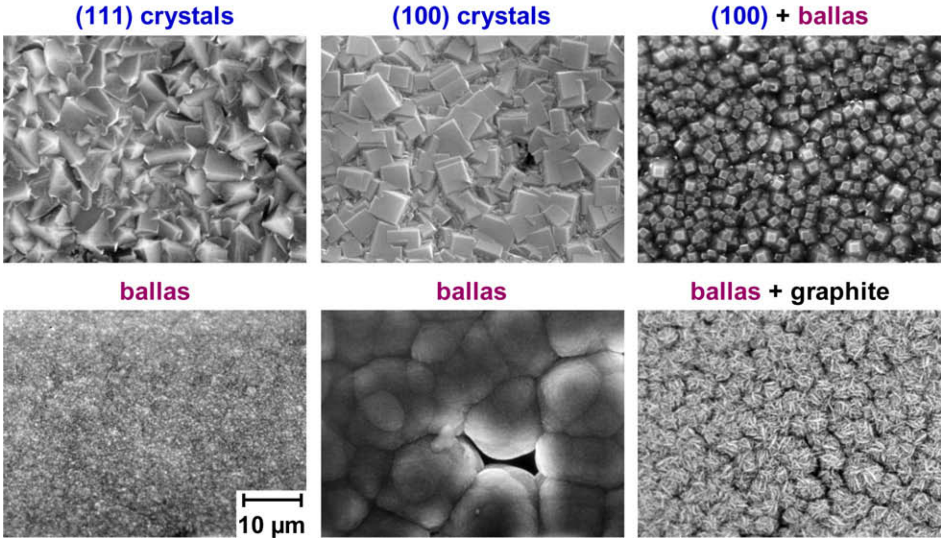

Fig. 1. Morphologies of CVD-diamond coatings grown at different deposition conditions.