INTERNATIONAL STANDARD

ISO 22180

First edition
2019-01

CVD diamond tools — Categorization

Outils diamant CVD — Catégorisation

STANDARDSISO.COM : Click to view the full PDF of ISO 22180:2019

Reference number
ISO 22180:2019(E)

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Published in Switzerland

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Foreword

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This document was prepared by Technical Committee ISO/TC 29, *Small tools*, Subcommittee SC 9, *Tools with defined cutting edges, holding tools, cutting items, adaptive items and interfaces*.

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CVD diamond tools — Categorization

1 Scope

This document deals with diamond tools whose cutting edges are made of CVD diamond, either as a solid single piece or as a coating. The tool specifications are differentiated into CVD diamond-coated tools (CVD diamond thin-film coatings) and tools with a CVD diamond cutting insert.

According to ISO 513, CVD diamond tools can be classified under "hard coatings of hard metal and ceramic" and "binder-free polycrystalline diamond". In order to differentiate the CVD diamond tools from tools with monocrystalline synthetic or natural diamond (MCD or monocrystalline diamond) or with sintered diamond with a binder phase (PCD or polycrystalline diamond), the structure and characteristics of MCD and PCD tools with binder phase are also briefly described.

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2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
active brazing
process of joining diamond to a metallic substrate by means of a brazing alloy

Note 1 to entry: The brazing alloy contains so-called active elements (titanium, for example) which form unsaturated carbides with the carbon atoms of the diamond and in this way bond the diamond to the braze material. Brazing of this kind is carried out in a vacuum or in shielding gas atmosphere.

3.2
chemical vapour deposition
CVD
process for manufacturing diamond in most cases at low-pressure and deposition temperatures of 600 °C to 1 000 °C

Note 1 to entry: Polycrystalline, binder-free diamond coatings and even monocrystals can be produced.

3.3
high-pressure high-temperature synthesis
HPHT synthesis
method of manufacturing diamond at a pressure of approximately 6 GPa and temperatures, T, between 1 400 °C and 1 800 °C

Note 1 to entry: It is only possible to manufacture monocrystals by HPHT synthesis.

3.4
monocrystalline diamond
MCD
cutting material made of diamond in natural or synthetic modification [from *HPHT synthesis* (3.3)]

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3.5
polycrystalline diamond
PCD
diamond-cutting material which is manufactured by a two-stage high-pressure high-temperature sintering process [*HPHT synthesis* (3.3)]

Note 1 to entry: The diamond crystallites which are produced in different crystallite sizes in the first step (through HPHT synthesis) are sintered into a cobalt matrix in the second step.

3.6
blank
diamond crystallites which are produced in different crystallite sizes in the first step are sintered into a cobalt matrix in the second step

Note 1 to entry: Due to the conditions of synthesis, the blank is a cylindrical disk with a thickness, s_D, of 300 µm to 2 000 µm.

3.7
cutting insert
platelet made of super-hard cutting material which is brazed onto a *tool holder* (3.9) and is used as a cutting part

3.8
cemented carbide
substrate material that consists of a hard metal phase and a binder phase for use as *CVD* (3.2) diamond coated thin film cutting tools

Note 1 to entry: Monotungsten carbide (WC) as hard metal combined with cobalt (Co) as a binder phase are commonly referred to as WC-Co. Cemented carbides may also consist of three phases: the Monotungsten carbide phase (WC) as the alpha phase, the binder phase (Co, Ni, etc.) as the beta phase and any other individual or combined carbide (TiC, Ta, NbC, etc.) as the gamma-phase.

3.9
tool holder
disposable insert or tool shank of which a corner has been ground away and a super-hard *cutting insert* (3.7) brazed on

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4 Classification of CVD diamond tools

4.1 CVD diamond-coated tools

Tools made of CVD diamond can be subdivided into two types: CVD diamond coated tools (CVD diamond thin-film tools) in which a coating with thickness, s_D, normally between 1 µm and 40 µm is directly deposited on the tool body, reproducing its shape, and tools with a CVD diamond cutting insert. Figure 1 shows the structure of a CVD diamond coating. An example of a CVD diamond coated tool is shown in Figure 2.

The manufacturing process of the synthesis CVD diamond is represented in Annex A.

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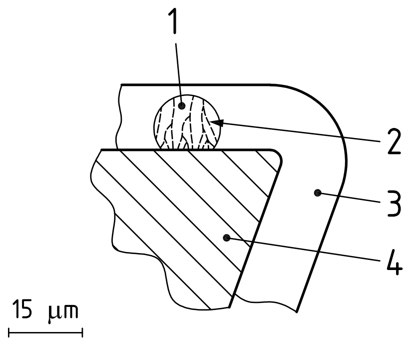

Key

1 diamond grain
2 grain boundary
3 CVD diamond film
4 tool substrate

Figure 1 — Structure of CVD diamond coating

Figure 2 — Example of CVD diamond-coated tool

CVD diamond coating modifications are displayed in Annex B.

4.2 CVD diamond thick film tools

CVD diamond thick film tools consist of a self-supporting, polycrystalline diamond layer normally between 20 µm and 2 000 µm thick, which is deposited and then cut into geometric sections, as shown in Figure 3. Like PCD, they are then, in a further operation, brazed as cutting inserts onto a tool holder (Figure 4). The key difference to PCD blanks is that no binder is necessary.

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Key

1 diamond grains

2 grain boundary

a Polished side of substrate.

Figure 3 — Structure of CVD diamond thick film

Structure and characteristics of MCD and PCD tools are represented in Annex C.

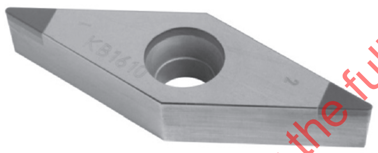

Figure 4 — Example of CVD diamond thick film tool

Since 2005, low-pressure synthesis (CVD process) has also been used for synthesizing monocrystalline CVD diamond (CVD-MCD). This diamond modification has applications in electronics and optics and as well as in machining technology, as shown in Figure 3.

4.3 Classification of CVD diamond tools

Table 1 shows a common example of classification of CVD diamond tools.

NOTE The use of CVD diamond tools is not limited to the examples given in Table 1.

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Table 1 — Classification of CVD diamond tools

	Classification of CVD diamond tools	
	CVD diamond-coated tools	**CVD diamond thick film tools**
Thickness, s_D (µm)	1 to 40	20 to 2 000
Substrate material	WC-Co cemented carbide with cobalt with a maximum mass fraction of 12 %. Amongst ceramic substrates, silicon-based ceramics.	Silicon has established itself as a disposable substrate, and molybdenum as a reusable substrate. In addition, titanium or copper alloys are possible substrate materials.
Carrier material		CVD diamond brazable material
Applicable tools	Drills, tapping tools and shank cutters, microtools, large-diameter tools, indexable inserts for turning and milling operations, sinusoidal.	Disposable inserts for turning, drilling and milling as well as in rotating-shaft tools
Post-treatment (Final processing)	The aim of post-treatment is to give the tool the cutting edge radius required for the cutting or chip-removal application or to create a friction-minimized surface on the normally raw growth side of the diamond film.	As a rule, the high quality requirements can only be satisfied by the mechanical processes of grinding, lapping and polishing as the final processing step.[a]

[a] For a long time a characteristic feature of these diamond tools included the production with only two-dimensional cutting-edge geometries. At present they can also be produced with complex or 3-dimensional cutting-edge geometries. An additional geometric modification of diamond cutting parts can be obtained by laser cutting or, in the case of electrically conductive CVD diamond, by electrical discharge machining (EDM) in order to create cutting-edge contours or chip grooves. EDM is made possible by doping with boron during the deposition process.

Manufacture of CVD diamond-coated tools is listed in Annex D.

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Annex A
(informative)

Manufacturing processes — Synthesis of CVD diamond

CVD techniques allow diamond to be deposited directly onto a series of materials and base geometries. Particularly in the field of machining, where higher performance and improved cost effectiveness in processing new, difficult to machine materials are always demanded, a series of CVD diamond tools has been developed and become commercially available.

Polycrystalline CVD diamond from gas phases is usually manufactured in the low pressure range between 1 hPa and 100 hPa. Either a plasma or a thermal activation of the gas phase is required. Processes which are in industrial use for the deposition of CVD diamond thin film are the hot-filament CVD process and the high-current arc plasma CVD process. For CVD diamond thick film, plasma processes with microwave or direct current (DC) excitation are typically employed.

In hot-filament CVD diamond deposition (HFCVD) the gas phase is activated by filaments of tungsten, tantalum or another refractory metal at filament temperatures of approximately 2 000 °C to 2 800 °C. In plasma-assisted CVD methods (PACVD), microwave plasmas (MW PACVD) or direct-current plasmas (DC PACVD) are usually employed for gas-phase activation. The gas phase to be activated consists for the most part of hydrogen plus an admixture of methane or another hydrocarbon as a source of carbon. This admixture falls within the range of a volume fraction of 0,5 % to 5 %.

Diamond deposition rates depend on the one hand on the activation process the associated CVD process parameters and on the other hand on the materials and geometries to be coated. In the field of CVD diamond tools, deposition rates range from values of around 0,3 µm/h up to some 10 µm/h in the fabrication of CVD diamond thick film by plasma-activated methods.

Electrical conductivity – and thus the electrical discharge machining of CVD diamonds – can be achieved by doping: boron is incorporated during diamond deposition. Doping can have various effects on the behaviour of CVD diamonds used as a cutting material, however.

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Annex B
(informative)

CVD diamond coating modifications

As a way of improving performance of CVD diamond coatings, according to VDI 2840, CVD coating technology offers the possibility of various diamond coating modifications. The different modifications have differing material properties and can, as such, determine the properties of the cutting tool. Free-standing CVD diamond thick-film has microcrystalline film morphology whereas CVD diamond thin-film systems are classified into microcrystalline, nanocrystalline and multilayer systems.

Microcrystalline films have grains with a columnar structure, having fewer grain boundaries which means that the highest CVD diamond thin-film quality and resistance to abrasive wear can be obtained. Due to the smaller size of the crystallites, nanocrystalline diamond films have a larger number of grain boundaries (see Figure B.1). Figure B.2 shows the fracture face of a nanocrystalline diamond film. These coatings are characterized by low surface roughness, good frictional properties and high resistance to adhesive wear, and are eminently suitable for post-deposition processing. Resistance to cracking is also improved since the high number of grain boundaries makes it more difficult for cracks to propagate.

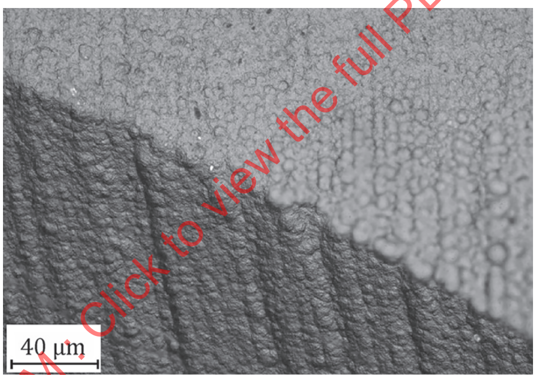

Figure B.1 — Cutting edge with CVD diamond coating (example)

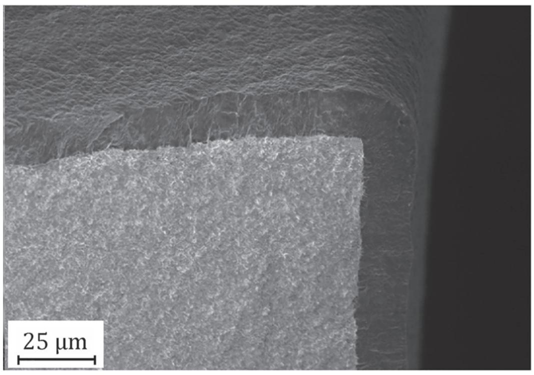

Figure B.2 — Carbide substrate and diamond coating (example)

If the process conditions for depositing microcrystalline and nanocrystalline diamond films are alternated during the coating process a diamond multilayer coating with an almost identical surface quality as is obtained with pure nanocrystalline diamond films results (see Figure B.3). Adhesion and cracking resistance is further improved since any cracks which do occur will propagate along the individual film layers and thus not reach the interface, the connection of substrate and coating.

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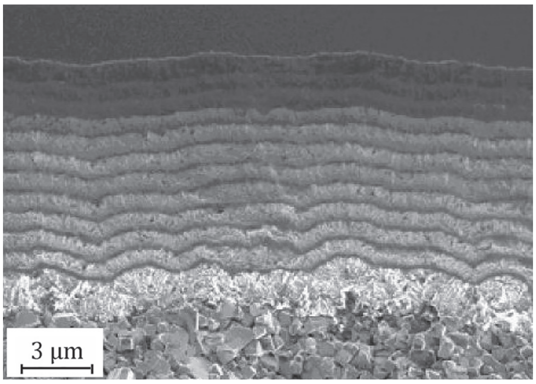

Figure B.3 — Example of fracture surface of a diamond multilayer film consisting of individual nanocrystalline and microcrystalline layers on a cemented carbide substrate

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Annex C
(informative)

Structure and characteristics of MCD and PCD tools

C.1 Structure and characteristics of MCD tools

Tools based on natural diamond or diamonds produced via high-pressure high-temperature synthesis (HPHT synthesis) have been used successfully for a number of decades in difficult machining tasks. With these diamond tools, either relatively large crystallites or so-called PCD sintered blanks are attached by various methods to base bodies or bonded to the tool surfaces in metal, ceramic or polymer matrixes.

MCD is single-crystal diamond in its typical cubic, octahedral or dodecahedral form which either grows naturally and is obtained by mining or was manufactured synthetically. On the industrial scale, the corresponding manufacturing process is HPHT synthesis.

As a cutting insert the MCD, usually oriented to the crystal axes, is brazed, sintered or clamped onto a tool holder. The cutting edge geometry of the MCD is given a final grinding before or after attachment. In industrial machining MCD is used primarily for obtaining the very best surface qualities during finishing operations. It is frequently used in the production of optical and high-precision mechanical components as well as in the jewellery, plastic, timber and glass industries. Figure C.1 shows an example of MCD in its raw and sawn states. Figure C.2 shows an example of MCD as an attached cutting edge used in turning. As a rule the length of the cutting edge of the MCD measures between 1 mm and 14 mm.

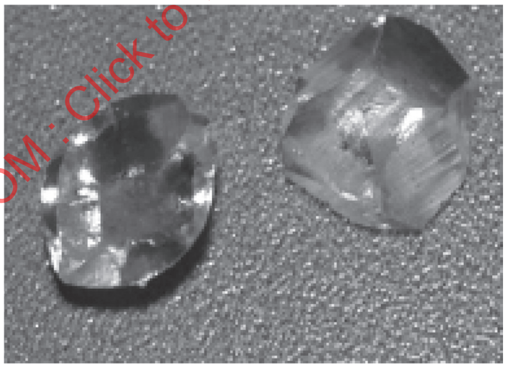

Figure C.1 — Example of vacuum-brazed MCD in raw and sawn state

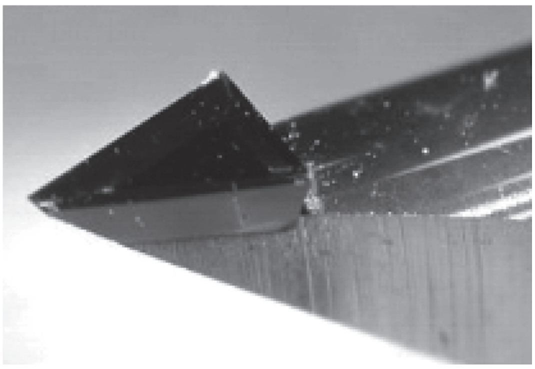

Figure C.2 — Example of attached MCD cutting edge

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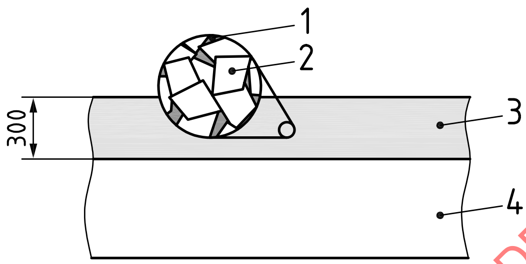
C.2 Structure and characteristics of PCD tools

C.2.1 General

PCD is a sintered composite material consisting of diamond crystallites dispersed in a binder matrix (see Figure C.3). A large number of modifications exist, in which binder and crystallite sizes are varied. This allows the properties of the cutting material to be tailored to the application case. The sintered blanks bonded to cemented carbide substrates are cut into individual parts and brazed onto tool holders as cutting inserts (see Figure C.4) by induction brazing. Sintered blanks without a cemented carbide substrate can be vacuum-brazed but this depends to a considerable extent on the heat resistance of the product. Unlike MCD, PCD is suitable not only for finishing but also for roughing operations, thereby greatly expanding the application fields of diamond in machining.

Dimensions in micrometres (µm)



Key

1 binder

2 diamond

3 PCD

4 cemented carbide

Figure C.3 — Schematic structure of PCD tool

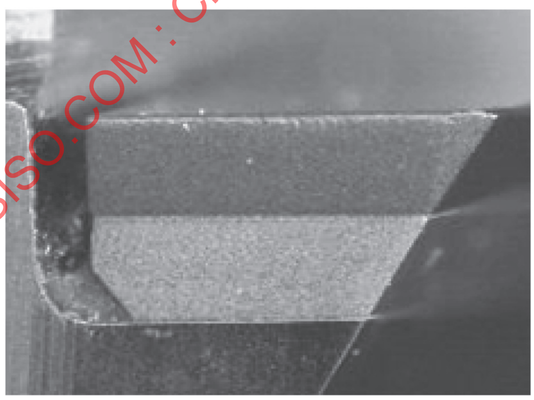


Figure C.4 — Brazed-on with cemented carbide substrate (example)

The methods used for affixing MCD and PCD to tools usually ensure very good adhesive strength. The manufacturing process and the material properties of MCD and PCD result in a limitation with regard to the geometrical tool complexity, however. In addition, with some machining tasks, it appears that the PCD binder used can represent a weak point with regard to abrasive tool wear.

C.2.2 CVD diamond-coated tools

In addition to the excellent diamond properties obtained, CVD diamond coated tools have the advantage of offering geometric flexibility, as coatings can be deposited on drills, tapping tools and shank cutters, microtools and even large-diameter tools. CVD diamond coated tools indexable inserts are also used

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in turning and milling operations and as blades in cutting operations. The manufacturing process can be broken down into pre-treatment of the substrate, the CVD deposition process and an optional post-deposition machining of the surface structure.

C.2.3 CVD diamond thick film tools

Unlike PCD, which contains various binders, binder-free CVD diamond offers greater hardness and wear resistance and also greater hot hardness and thermal conductivity. In comparison with PCD, the fracture toughness is lower.

Microcrystalline diamond blanks are produced by means of a CVD process. The blanks are then cut into individual cutting inserts, usually by a laser. After being brazed in a vacuum onto a tool base body, the cutting inserts are then ground. Due to their high film thickness, diamond tools produced in this way have a high stability and a considerably higher wear volume in comparison with CVD diamond-coated tools. The adhesion of the cutting insert is only limited by the adhesion quality of the braze.

Like PCD, it is a characteristic feature of these diamond tools that they can only be produced with two-dimensional cutting-edge geometries. As a cutting insert, CVD diamond thick film is used in disposable inserts for turning, drilling and milling as well as in rotating-shaft tools. An additional geometric modification of diamond cutting parts can be obtained by laser cutting or, in the case of electrically conductive CVD diamond, by electrical discharge machining (EDM) in order to create cutting-edge contours or chip grooves.

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Annex D
(informative)

Manufacture of CVD diamond-coated tools

D.1 Manufacture of CVD diamond-coated tools

CVD coating technology allows the cost effective deposition of coatings onto three dimensional geometries including microgeometries, as well as large areas. Although the relatively high deposition temperatures (approximately 600 °C to 1 000 °C) permit coating of only a limited selection of materials, coating deposition can nevertheless be adapted to geometrically very diverse parts. The hot-filament CVD technique is primarily used on account of its greater flexibility compared with plasma methods as well as the lower thermal stresses induced. By this process, it is possible on the one hand to coat rotating tools, for example, tools with very small dimensions, and on the other hand to coat large numbers of indexable inserts.

Substrate selection:

Cemented carbide is the most commonly implemented substrate material for CVD diamond tools used in machining. As a rule, tungsten carbide-cobalt (WC-Co) cemented carbide with cobalt with a maximum mass fraction of 12 % can be coated. The reason for this restriction is that under the extreme conditions of CVD diamond coating, cobalt has a detrimental chemical effect on diamond synthesis. For this reason, the cobalt close to the surface needs to be reduced before diamond coating takes place.

The composition of the cemented carbide and the grain sizes of the carbides need to be known before the appropriate pre-treatment can be selected and the diamond coating process optimised accordingly. Coating adhesion can be assisted by a defined surface topography created by the pre-treatment process.

Companies which offer CVD diamond coatings maintain lists showing the types of cemented carbides to which the pre-treatment and coating processes can be adjusted. Since the cemented carbide producers can modify these types, lists are updated and expanded regularly. These lists are often available on the internet or can be obtained from coating companies. It has even been possible to develop processes for the coating of fine and very fine cemented carbide grain types. The service life of these hard and yet ductile materials can be extended significantly through the deposition of a CVD diamond coating.

Ceramic and other substrate materials can also be employed, however these are used to a much lesser extent than cemented carbide. Amongst ceramic substrates, silicon-based ceramics are particularly suited to diamond coating. Very good adhesion of the diamond coating is assured not only by mechanical interlocking but is also assisted by the chemical bond between the ceramic and the diamond coating.

Silicon can also be used as a substrate material in the industrial manufacture of cutting blades. Although steel can, with some additional effort be coated, account needs to be taken in particular of the reaction of the steel with the activated gas phase, the high deposition temperatures and the high stresses arising from differences in the coefficients of thermal expansion.

Table D.1 is an example of manufacture of CVD diamond-coated tools.

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Table D.1 — Example of manufacture of CVD diamond-coated tools

Methods of coating	thin-film		thick-film	
			In plasma-assisted CVD methods(PACVD)	
	hot-filament CVD diamond deposition (HFCVD)	high-current arc plasma CVD process	microwave plasmas (MW PACVD)	direct-current plasmas (DC PACVD)
Filaments	Tungsten, tantalum, or another refractory metal			
Filament temperature	2 000 °C to 2 800 °C			
Classification of CVD diamond	Fine, nanocrystalline, multilayer structure		Fine, polycrystalline (application in electronics and optics)	
Synthesis pressure	1 hPa to 100 hPa			
Raw gas	Atmosphere: hydrogen Source of carbon: methane or hydrocarbon Admixture range: volume fraction of 0,5 % to 5 %			
Deposition rate	0,3 µm/h to 10 µm/h			
Deposition temperatures	600 °C to 1 000 °C			
Electrical conductivity	EDM is made possible by doping with boron during the deposition process.			
Substrate material	Cemented carbide, silicone-based ceramics			
Pre-treatment (including intensive cleaning)	In many cases, the surface is roughened so as to improve mechanical keying or interlocking of the coating.			

D.2 Pre-treatment

Before the actual CVD diamond coating process can begin, the substrates need to be pre-treated. This includes, at least, intensive cleaning. In many cases, the surface is roughened so as to improve mechanical keying or interlocking of the coating. In the case of cemented carbide the cobalt binder needs to be removed from the interface zone through blasting and/or etching since it has a detrimental effect on diamond growth. Frequently, the final pre-treatment step is seeding with diamond particles to provide starting points for the growth of the coating.

Pre-treatment of cemented carbide involves single- or multi-stage mechanical, chemical and/or thermal treatments. In this regard, each coating company has its own methods. In addition to the removal of cobalt as already discussed, this also often creates a surface structure with undercuts which results in an interlocking of the diamond with the hard WC grains. Particle blasting is a common form of mechanical pre-treatment and at the beginning of pre-treatment serves to even out the surface and to prepare the cutting edges.

A further method for improved coating adhesion of the diamond coating is the deposition of interlayers in the form of for example titanium or silicon based coatings. This renders the costly and time-consuming etching of the cemented carbide unnecessary.

D.3 Post-treatment

In the case of tools with a geometrically defined cutting edge, direct CVD diamond coating results in rounding of the cutting edge and, with microcrystalline films, in high surface roughness. With CVD diamond tools, edge rounding need not be automatically regarded as a disadvantage: Sharp, conventional tools round off very quickly in use while CVD diamond coated tools retain their initial rounding almost throughout the tool life. Moreover, with overly sharp edges, cutting edge chipping will occur more easily.

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