

**CUTTING TOOL****Technical Field**

The present invention relates to the field of coated sharp-  
5 edged cutting tools made of or comprising a sintered body  
embracing at least a hard material and a binder material  
which has been sintered under temperature and pressure to  
form the body. Cutting tools comprise, e.g., tools for  
milling (milling tools), turning tools, indexable inserts,  
10 gear cutting tools, hobs, shank type tools, tool for  
threading, tapping tools.

**Background of the Invention**

With past and current sintering technology of powder  
15 metallurgy, cemented carbide cutting tools have been used  
both in uncoated and in CVD (chemical vapor deposition) and  
PVD (physical vapor deposition) coated conditions. CVD  
coating processes including MT-CVD (moderate temperature CVD  
or medium temperature CVD) coating processes need high  
20 temperatures, usually above 950°C for HT-CVD (high  
temperature CVD) or between 800° C and 900° C for MT-CVD,  
and a chemically aggressive process atmosphere. This has,  
amongst others, well known drawbacks with reference to  
transverse rupture strength (TRS) and low edge strength of  
25 the cutting tools as well as to unavoidable thermal cracks  
of the coating.

A closer look to the drawbacks of HT-CVD should be given in the following with the coating of cemented carbides taken as an example:

- a) As mentioned before, reduction of TRS of the substrate  
5 may be due to the fact that the state of the surface  
prior to coating is one of residual compressive stress  
induced by the correct grinding process, which is  
beneficial; this state is altered by high temperature  
which relieves this beneficial residual compressive  
10 stress. Therefore, independent of the coating, high  
temperature annealing has this effect on the carbide  
substrate. However, even if the substrate is not properly  
ground - for instance, if it is subjected to "abusive  
grinding" which leaves residual tensile stress or even  
15 some surface cracks - the high temperature treatment has  
essentially no beneficial effect.
- b) A further reduction of the TRS of the coated tool  
originates from the presence of thermal cracks induced by  
thermal expansion mismatch between the coating and  
20 substrate upon cooldown from the high CVD temperature.  
The cracks run through the thickness of the coating, and  
thus can initiate fatigue failure under certain cutting  
conditions.
- c) In the case of WC-Co hardmetals, it is also known that  
25 cobalt diffuses towards the surface with temperatures of  
about 850° C and above, which is also associated with  
decarburization and eta phase formation during the CVD  
process. Such eta phase can e.g. be formed by the  
decarburization of the outer region of the substrate in  
30 the initial formation of TiC or TiCN CVD first layer  
which is the usual underlayer for CVD Al<sub>2</sub>O<sub>3</sub> coating

layer. The eta phase region forms an embrittled layer of high porosity, again causing micro-cracking initiation sites as well as coating delamination tendency. At least this drawback of HT-CVD has been overcome with MT-CVD  
5 e.g. by applying a first TiCN layer at about 850° C, thereby minimizing substrate eta phase formation.

Therefore, different measures have been taken to diminish such detrimental effects. US 4,610,931 suggests to use cemented carbide bodies having a binder enrichment near the  
10 peripheral surface. In US 5,266,388 and US 5,250,367, application of a CVD coating being in a state of residual tensile stress followed by a PVD coating being in a state of residual compressive stress has been suggested for the mentioned binder enriched tools.

15 Despite the fact that cemented carbides have been used to illustrate the drawbacks of CVD coating processes above, the same or at least similar problems are known from other substrates having sintered bodies. Cermets also have Co, Ni (and other metals like Mo, Al, ...) binders and undergo a  
20 sintering process similar to cemented carbides. TiCN-based cermets e.g. are not as readily CVD-coated today since these substrates are more reactive with the coating gas species, causing an unwanted reaction layer at the interface. Superhard CBN tools use high-temperature high-pressure  
25 sintering techniques different from that used for carbides and cermets. However, they may also have metallic binders such as Co, Ni,... tending to high temperature reactions during CVD coating processes. These substrates are sometimes PVD-coated with TiN, TiAlN, CrAlN or other coating systems  
30 mostly for wear indication at the cutting edges. Such coatings however can only give a limited protection against high temperature and high oxidative stress caused by high

cutting speeds applied with state of the art turning machines for example.

Ceramic tool materials based on solid  $\text{Al}_2\text{O}_3$ ,  $\text{Al}_2\text{O}_3\text{-TiC}$ ; or  $\text{Al}_2\text{O}_3\text{-Si}_3\text{N}_4$  (SiAlON) that incorporate glassy phases as  
5 binders represent another tool type: tools which are electrically insulating and therefore difficult to coat also with conventional PVD. These materials are sinter-HIPped (HIP: hot isostatic presssing), as opposed to lower-pressure sintered carbides. Such ceramic inserts again are not CVD  
10 coated because high temperature can cause softening of the  $\text{Si}_3\text{N}_4$  substrate or cause it to loose some toughness as the amorphous glassy binder phase becomes crystalline. Uncoated materials however can allow interaction during metal cutting between their binder phases and the workpiece material and  
15 therefore are susceptible to cratering wear restricting use of such tools to limited niche applications.

Therefore, PVD coatings have replaced CVD coatings partially or even completely for many operations with high demands on  
20 tool toughness or special needs on geometry. Examples for such tools are tools used for interrupted cut applications like milling or particularly sharp-edged threading and tapping tools. However, due to outstanding thermochemical resistivity and hot hardness, oxidic CVD-coatings such as,  
25 e.g.  $\text{Al}_2\text{O}_3$  in  $\alpha$ - and/or  $\gamma$ -crystal structure, or thick multilayers comprising such coatings, are still in widespread use especially for rough-medium turning, parting and grooving applications in all types of materials and nearly exclusively with turning of cast iron. Such coatings  
30 could not be produced by PVD processes until recently due to principal process restrictions with electrically insulating materials and especially with oxidic coatings.

As is well known to those skilled in the art, all the problems mentioned above tend to occur and focus on the cutting edge becoming more acute with the smaller radius of the cutting edge. Therefore, to avoid edge chipping or  
5 breaking with CVD coated tools, additional geometrical limitations have to be considered for cutting edges and tool tips, with cutting edges limited to a minimum radius of 40  $\mu\text{m}$  for cemented carbides for example. Additionally, further measures like applying a chamfer, a waterfall, a wiper or  
10 any other special geometry to the clearance flank, the rake face or both faces of the cutting edge are commonly used but add another often complex-to-handle production step to manufacturing of sintered tool substrates.

#### 15        **Summary of the Invention**

It is therefore an object of the invention to provide a single or a multilayer PVD coated sharp edged cutting tool, which can at the same time exhibit satisfactory wear and thermochemical resistance as well as resistance to edge  
20 chipping. The cutting tool comprises a sintered body made of a cemented carbide, a CBN, a cermet or a ceramic material having a cutting edge with an edge radius  $R_e$ , a flank and a rake face and a single or a multilayer coating consisting of a PVD coating comprising at least one oxidic PVD layer  
25 covering at least parts of the surface of the sintered body.

In one embodiment, the edge radius  $R_e$  is smaller than 40  $\mu\text{m}$ , preferably smaller than or equal to 30  $\mu\text{m}$ . The covered parts of the surface comprise at least some parts of the sharp edge of the sintered body. It should be mentioned that if  
30 after sharpening of the tool there is not any posttreatment like honing, blunting or the like applied, an edge radius  $R_e$

equal or even smaller than 20  $\mu\text{m}$  can be fabricated on sintered tools. Also these tools can be coated beneficially with oxidic PVD coatings as there is not any harmful influence of the coating process, and weakening of the cutting edge does not occur.

The coating is free of thermal cracks and does not contain any halogenides or other contaminations deriving from CVD process gases. Additionally, the coating or at least the oxidic PVD layer can be free of inert elements like He, Ar, Kr and the like. This can be effected by vacuum arc deposition in a pure reactive gas atmosphere. As an example for a multilayer coating, deposition of an adhesion layer and or a hard, wear protective layer can be started in a nitrogen atmosphere followed by a process step characterized by growing oxygen flow to produce a gradient towards the oxidic coating accompanied or followed by a ramp down or shut down of the nitrogen flow. Applying a small vertical magnetic field over a surface area of the cathodic arc target may be beneficial in case of highly insulating target surfaces formed e.g. by arc processes under pure oxygen atmosphere. Detailed instructions how to perform such coating processes can be found in applications WO 2006-099758, WO 2006-099760, WO 2006-099754, as well as in CH 1166/03 which hereby are incorporated by reference to be a part of the actual disclosure.

The oxidic layer will preferably incorporate an electrically insulating oxide comprising at least one element selected from the group of transition metals of the IV, V, VI group of the periodic system and Al, Si, Fe, Co, Ni, Y, La.  $(\text{Al}_{1-x}\text{Cr}_x)_2\text{O}_3$  and  $\text{Al}_2\text{O}_3$  are two important examples of such materials. Crystal structure of such oxides can vary and may comprise a cubic or a hexagonal lattice like an alpha ( $\alpha$ ),

beta ( $\beta$ ), gamma ( $\gamma$ ), delta ( $\delta$ ) phase or a spinel-structure. For example, oxide layers comprising films of different oxides can be applied to the tool. Despite of the fact that multilayer coatings may comprise nitrides, carbonitrides, oxinitrides, borides and the like of the mentioned elements having sharp or graded transfer zones between defined layers of different elemental or stoichiometric composition, it should be mentioned that best protection against high temperature and/or high oxidative stress can be ensured only by a coating comprising at least one layer consisting of essentially pure oxides.

Forming a thermodynamically stable phase, the corundum type structure which for example can be of the type  $\text{Al}_2\text{O}_3$ ,  $(\text{AlCr})_2\text{O}_3$ ,  $(\text{AlV})_2\text{O}_3$  or more generally of the type  $(\text{Me}_1_{1-x}\text{Me}_2_x)_2\text{O}_3$ , with  $0.2 \leq x \leq 0.98$  and Me1 and Me2 being different elements from the group Al, Cr, Fe, Li, Mg, Mn, Nb, Ti, Sb, V, will be a preferred embodiment of the oxidic layer. Detailed instructions how to create such corundum type single or multilayered structures can be found in application CH 01614/06 which hereby is incorporated by reference.

In an embodiment of the invention, the coating comprises an adhesion layer situated directly on the body surface, and/or at least one hard wear protective layer situated between the body and the oxidic layer or between two or more consecutive oxidic layers and/or on top of the coating layers. The adhesion layer as well as the wear protective layer therein preferably comprises at least one element of the group of a transition metal from group IV, V, VI of the periodic system of the elements and of Al, Si, Fe, Ni, Co, Y, La. The compounds of the wear protective layer will further comprise N, C, O, B or a mixture thereof, wherein N, C and CN are

preferred. Examples of such wear protective layers are TiN, TiC, CrN, CrC, TiAlN, CrAlN, TiCrAlN as well as TiCN, CrCN, TiAlCN, CrAlCN, TiCrAlCN.

Compounds of the adhesion layer may comprise N, C, O or a  
5 mixture thereof, wherein N and O is preferred. Examples of such adhesion layers are TiN, CrN, TiAlN, CrAlN, TiCrAlN or TiON, CrON, TiAlON, CrAlON, TiCrAlON. The thickness of the adhesion layer will be preferably between 0.1 and 1.5  $\mu\text{m}$ . If the adhesion layer comprises a thin metallic layer situated  
10 directly on the body surface, the thickness of the metallic layer should be between 10 and 200 nm for an optimized tool-to-coating bond. Examples of such metallic interlayers are Ti, Cr, TiAl or CrAl. Overall coating thickness will be between 2 and 30  $\mu\text{m}$ , and due to economy of the coating  
15 process in most cases rather between 3 to 10  $\mu\text{m}$ . However, it should be mentioned that in principle, tools can be provided with even thicker coatings if there is a need for some special applications which might be high speed turning in cast iron, for example.

20 Another embodiment of the invention may encompass a wear protective layer comprising at least one composition-segregated film embracing a phase having a relatively high concentration of a specific element fostering phase segregation of crystal structures like Si or B for example,  
25 and a phase having a relatively low concentration of such a specific element. In one embodiment, the phase having a relatively high concentration of the specific element constitutes an amorphous or microcrystalline phase. Such films will preferably comprise a nitride or carbonitride of  
30 a combination of Cr and Si or of Ti and Si.

All layers may be deposited according to the actual needs with sharp or gradient layer-to-layer transition zones forming coatings showing a discrete or a gradient layer structure. Thickness of layers may be chosen from several  
5 micrometers down to a few nanometers if such structures should be preferable for specific applications.

Contrary to cutting tools comprising oxidic CVD layers, such PVD coated tools need no binder-enriched substrates to minimize the adverse effect of the CVD process to the TRS  
10 (transverse rupture strength) of the sintered body. Low process temperatures with PVD processes and the possibility to apply coatings or certain layers, in particular the before-mentioned wear protective layers, in a state of compressive stress proved to be useful measures against  
15 crack propagation and the risk of edge chipping. Therefore, there is no longer use for binder-enriched substrates for the majority of the actual cutting applications, which is an evident simplification for carbide tool production.

However, under certain cutting conditions, even PVD coated  
20 enriched carbide grades might be useful, for example if cutting parameters should be extended such that higher feed force is applied and an even higher TRS would be preferred.

Due to the potential higher TRS of such PVD coated hardmetal grades, not only cutting tools having a very small edge  
25 radius but also cutting tools having a smaller nose radius or point angle can be produced for special fine tooling applications. As an example, compared to conventional cemented carbide inserts having common nose radii of minimal 0.2 mm (0.008 inch) to 2.4 mm (0.094 inch), even radii like  
30 0.15, 0.10, 0.05 and 0.01 mm could be coated and tested

under usual fine turning conditions without signs of premature tip chipping.

Due to inherent "geometric" properties of PVD processes, a further coating feature can be given to certain sintered  
5 bodies of simple geometry - as e.g. inserts - solely by using defined fixturing systems, thereby exposing certain areas of the body to a "direct" ions and/or neutrals flow - in the following referred to as particle flow - from the arc or sputter source, whereas other areas are essentially hit  
10 by grazing or indirect incident only. In this context "direct" means that an essential part or the majority of the particles emitted by the arc source hit the surface in an angle of about  $90 \pm 15^\circ$ . Therefore, layer growth on such areas is faster than growth on areas exposed to a substantially  
15 "indirect" particle flow. This effect can be used to apply coatings of varying thickness during one PVD coating process; which is completely different from CVD processes providing a uniform coating thickness on every surface independent of geometric effects due to different  
20 substrate/source positioning.

For example, using a threefold rotating spindle to fix center holed square 13x13x5 mm inserts alternating with 8 mm spacers, a ratio of the flank face thickness ( $d_{\text{Flank}}$ ) and the rake face thickness ( $d_{\text{Rake}}$ ) of about  $2 \pm 0.5$  could be adjusted  
25 for the inserts over the whole length of the substrate carousel of about 500 mm in a commercial Oerlikon coating unit of the RCS type, or of a length of about 900 mm in a commercially available Oerlikon BAI 1200 coating unit. Thickness measurements were made in the middle of the flank  
30 face and, for the rake face, at the bisecting line connecting two opposite noses of the insert in 2 mm distance from the cutting edges defining the point angle of the nose.

Such inserts having a quotient  $Q_{R/F} = d_{\text{rake}} / d_{\text{flank}} < 1$ , where  $d_{\text{rake}}$  is the overall coating thickness on the rake face and  $d_{\text{flank}}$  is the overall coating thickness on the flank face, are particularly convenient for milling tools which due to impact stress during milling operations profit from a higher PVD coating thickness on the flank face. This effect is intensified by PVD coatings having a high residual stress which can be controlled by process parameters like substrate bias, total pressure and the like.

Contrary to milling, wear resistance of turning operations benefits from a higher coating thickness on the rake face due to the high abrasive and thermochemical wear caused by the passing chip. Therefore, in this case, quotient  $Q_{R/F}$  should be higher than one:  $Q_{R/F} = d_{\text{rake}} / d_{\text{flank}} > 1$ . As for inserts, such a coating distribution can be produced by fixtures exposing the rake phase to direct particle flow of the arc or sputter source. Two-fold rotating magnetic fixtures, for example, can be used to expose a rake face of cemented carbide inserts directly to the source. This magnetic fixture results in additional thickness enhancement at the cutting edge which can be influenced by process parameters like substrate bias and can be utilized to improve the tool performance. For non-magnetic cutting plates, clamping or hooking fixtures can be used as required. Furthermore, for turning tools, a coating design comprising a wear protective layer made of TiN, TiC or TiCN, TiAlN or TiAlCN, AlCrN or AlCrCN situated between the body and the oxidic layer proved to be particularly effective.

Cutting tools according to the invention are applicable to a large variety of different workpiece materials as for instance all types of metals, like nonferrous metals but especially ferrous metals, cast iron and the like. Special

tools for milling or turning of such materials can be optimized as mentioned above. This makes PVD coatings a serious competitor to up-to-date CVD coatings even in until now untouched CVD fields like turning operations especially roughing and high speed finishing of steels and cast irons.

In many cutting applications, tools having an oxidic layer as the outermost layer of the coating system proved to be the best solution. This refers especially to gear cutting tools, hobs or different types of shank type tools including indexable shank type tools.

The following examples are intended to demonstrate beneficial effects of the invention with some special tools and coatings and are not intended in any way to limit the scope of the invention to such special examples. It should be mentioned that several tests have been performed in comparison to well-known applications where PVD coated tools are known to outperform CVD coatings for a long time as e.g. with threading and drilling in different types of metal materials, for dry and wet milling of non-ferrous materials, as well as for certain milling and turning applications on steel or super alloys. For such steel milling, low or medium speed up to 100 m/min but up to high feed rates from 0.2 till 0.4 mm/tooth has been applied. In most cases, tools according to the invention performed as well as or even better than well-known TiCN or TiAlN based PVD coated tools. However, one focus of the invention was to substitute CVD coatings in applications of high thermochemical and/or abrasive wear as for instance with high speed milling of iron, steel and hardened materials as well as turning of steel, iron, as e.g. cast iron, superalloys and hardened materials.

PVD coatings of the following examples have been deposited by a cathodic arc process; deposition temperature was between 500°C with comparative TiCN coatings and 550°C for oxidic coatings. For oxidic PVD coatings, substrate bias has  
5 been pulsed and a small vertical magnetic field having a vertical field component of 3 to 50 Gauss and an essentially smaller horizontal component has been applied. With experiments 25, 28, 35, 37 an additional pulse signal has been superimposed to the DC current of the  $\text{Al}_{0.6}\text{Cr}_{0.4}$   
10 ( $\text{Al}_{0.6}\text{V}_{0.4}$ ) arc sources. Details of such or similar applicable oxide coating processes can be found in WO 2006-099758 and the other before-mentioned documents incorporated by reference. Layer thickness of TiN and TiCN interlayers between the substrate and a top oxidic layer was between 0.5  
15 to 1.5  $\mu\text{m}$ .

Comparative CVD coatings have been deposited with MT-CVD and deposition temperatures of 850° C.

**Example A)** Milling of alloy steel AISI 4140 (DIN 1.7225)

20 Tool: indexable face mill, one insert  $z=1$   
Tool diameter:  $d = 98 \text{ mm}$   
Cutting speed:  $v_c = 152 \text{ m/min}$   
Feed rate:  $f_z = 0.25 \text{ mm/tooth}$   
Depth of cut:  $d_c = 2.5 \text{ mm}$   
25 Process: down milling with coolant  
Insert type: Kennametal SEHW 1204 AFTN, 12 wt% Co;  
chamfered sharp cutting edges for PVD  
coating, chamfered and honed to a very  
slight 40  $\mu\text{m}$  radius for CVD coating.

Table 1)

| Exp. Nr. | Type  | d [μm] | Coating layers |                                    |                                    | Tool life [mm of cut] |
|----------|-------|--------|----------------|------------------------------------|------------------------------------|-----------------------|
| 1        | MTCVD | 5.0    | -              | TiCN                               | -                                  | 5.050±500             |
| 2        | PVD   | 3.5    | -              | TiCN                               | -                                  | 4.300±50              |
| 3        | PVD   | 3.5    | -              | TiAlN                              | -                                  | 4.550±80              |
| 4        | PVD   | 4.0    | -              | AlCrN                              | -                                  | 4.600±100             |
| 5        | PVD   | 4.5    | TiN            | (AlCr) <sub>2</sub> O <sub>3</sub> | -                                  | 5.100±90              |
| 6        | PVD   | 5.0    | TiN            | TiCN                               | (AlCr) <sub>2</sub> O <sub>3</sub> | 5.300±120             |

**Example B)** Milling of alloy steel AISI 4140 (DIN 1.7225)

5 Tool: indexable face mill, one insert z=1

Tool diameter: d = 98 mm

Cutting speed:  $v_c = 213$  m/min

Feed rate:  $f_z = 0.18$  mm/tooth

Depth of cut:  $d_c = 2.5$  mm

10 Process: down milling, no coolant

Insert type: Kennametal SEHW 1204 AFTN, 12 wt% Co;

Edge preparation see example A.

Table 2)

| Exp. Nr. | Type  | d [μm] | Coating layers |                                    |                                    | Tool life [mm of cut] |
|----------|-------|--------|----------------|------------------------------------|------------------------------------|-----------------------|
| 7        | MTCVD | 5.0    | -              | TiCN                               | -                                  | 9.300±800             |
| 8        | PVD   | 3.5    | -              | TiCN                               | -                                  | 8.000±150             |
| 9        | PVD   | 4.5    | TiN            | (AlCr) <sub>2</sub> O <sub>3</sub> | -                                  | 10.100±90             |
| 10       | PVD   | 5.0    | TiN            | TiCN                               | (AlCr) <sub>2</sub> O <sub>3</sub> | 10.300±100            |
| 11       | PVD   | 3.5    | TiN            | (AlV) <sub>2</sub> O <sub>3</sub>  | -                                  | 8.900±50              |
| 12       | PVD   | 4.0    | TiN            | TiCN                               | (AlV) <sub>2</sub> O <sub>3</sub>  | 9.400±80              |

15

**Example C)** Milling of alloy steel AISI 4140 (DIN 1.7225)

Tool: indexable face mill, one insert z=1

Tool diameter: d = 98 mm

20 Cutting speed:  $v_c = 260$  m/min

Feed rate:  $f_z = 0.20$  mm/tooth

Depth of cut:  $d_c = 3.125$  mm

Process: down milling

Insert type: Kennametal SEHW 1204 AFTN,

Exp.13,15,17,19 Co 6.0 weight% enriched  
carbide grade,10.4 weight% cubic  
carbides.

Exp. 14,16,18,20 Co 6.0 weight% non-enr.  
carbide grade, 10.4 weight% cubic  
carbides.

Edge preparation see example A.

Table 3)

| Exp.<br>Nr. | Type  | d<br>[ $\mu\text{m}$ ] | Coating layers |                                    |                                   | Tool life<br>[minutes] |
|-------------|-------|------------------------|----------------|------------------------------------|-----------------------------------|------------------------|
| 13          | MTCVD | 8.0                    | TiN            | TiCN                               | TiN                               | 12.1 $\pm$ 2.0         |
| 14          | MTCVD | 8.0                    | TiN            | TiCN                               | TiN                               | 6.0 $\pm$ 4.0          |
| 15          | PVD   | 4.0                    | -              | TiN                                | -                                 | 6.2 $\pm$ 2.0          |
| 16          | PVD   | 4.0                    | -              | TiN                                | -                                 | 5.5 $\pm$ 2.0          |
| 17          | PVD   | 4.5                    | TiN            | (AlCr) <sub>2</sub> O <sub>3</sub> | -                                 | 13.3 $\pm$ 1.5         |
| 18          | PVD   | 5.0                    | TiN            | (AlCr) <sub>2</sub> O <sub>3</sub> | -                                 | 12.1 $\pm$ 2.0         |
| 19          | PVD   | 3.5                    | TiN            | TiCN                               | (AlV) <sub>2</sub> O <sub>3</sub> | 14.6 $\pm$ 2.0         |
| 20          | PVD   | 4.0                    | TiN            | TiCN                               | (AlV) <sub>2</sub> O <sub>3</sub> | 13.8 $\pm$ 3.0         |

Example C, experiment 14 clearly shows the detrimental  
influence of the CVD process to non-enriched carbide grades,  
which is due to the mentioned process effects. On the other  
side, the beneficial influence of a Co-enriched surface zone  
shows only limited effects with PVD coatings. Advantage of  
PVD coatings comprising an oxidic layer is obviously as is  
with examples A and B.

**Example D)** Turning of stainless steel AISI 430F (DIN 1.4104)

Cutting speed:  $v_c = 200$  m/min

Feed rate:  $f_z = 0.20$  mm/tooth

Depth of cut:  $d_c = 1.0$  mm

Process: continuous turning of outer diameter

Insert type: Cermet grade, ISO VNMG 160408A11,  
sharp cutting edges for PVD coating,  
chamfered and honed to a slight 60  $\mu\text{m}$   
radius before CVD coating.

5

Table 4)

| Exp. Nr. | Type  | d [ $\mu\text{m}$ ] | Coating layers |                       |                       | Tool life [pieces per edge] |
|----------|-------|---------------------|----------------|-----------------------|-----------------------|-----------------------------|
| 22       | MTCVD | 8.0                 | -              | TiCN                  | -                     | 350 $\pm$ 55                |
| 22       | PVD   | 5.0                 | -              | TiN                   | -                     | 275 $\pm$ 10                |
| 23       | PVD   | 4.5                 | -              | (AlCr) $_2\text{O}_3$ | -                     | 340 $\pm$ 15                |
| 24       | PVD   | 6.0                 | TiN            | (AlCr) $_2\text{O}_3$ | -                     | 420 $\pm$ 25                |
| 25       | PVD   | 6.5                 | TiN            | TiCN                  | (AlCr) $_2\text{O}_3$ | 450 $\pm$ 30                |
| 26       | PVD   | 5.5                 | -              | (AlV) $_2\text{O}_3$  | -                     | 360 $\pm$ 20                |
| 27       | PVD   | 7.0                 | TiN            | (AlV) $_2\text{O}_3$  | -                     | 385 $\pm$ 20                |
| 28       | PVD   | 7.5                 | TiN            | TiCN                  | (AlV) $_2\text{O}_3$  | 410 $\pm$ 35                |
| 29       | PVD   | 3.0                 | -              | (AlZr) $_2\text{O}_3$ | -                     | 335 $\pm$ 20                |
| 30       | PVD   | 5.5                 | TiN            | (AlZr) $_2\text{O}_3$ | -                     | 380 $\pm$ 30                |
| 31       | PVD   | 6.0                 | TiN            | TiCN                  | (AlZr) $_2\text{O}_3$ | 380 $\pm$ 25                |

Additionally to the influence of the coating type and material, there can be seen a clear beneficial influence of  
10 layer thickness with oxidic PVD coatings. Nevertheless, even most thin oxidic PVD coatings show a better performance than the thick MT-CVD-coating of experiment 22.

**Example E)** Turning of grey cast iron

Cutting speed:  $v_c = 550 \text{ m/min}$

15 Feed rate:  $f_z = 0.65 \text{ mm/tooth}$

Depth of cut:  $d_c = 5.0 \text{ mm}$

Process: continuous turning of outer diameter

Insert type: Ceramic, Al $_2\text{O}_3$ -TiC 20%, ISO RNGN 120400T,  
sharp cutting edges for PVD coating,  
20 chamfered and honed to a slight 50  $\mu\text{m}$   
radius before CVD coating.

Table 5)

| Exp. Nr. | Type  | d [ $\mu\text{m}$ ] | Coating layers |                             |                             | Tool life [pieces per edge] |
|----------|-------|---------------------|----------------|-----------------------------|-----------------------------|-----------------------------|
| 32       | MTCVD | 8.0                 | TiCN           | $\text{Al}_2\text{O}_3$     | -                           | 23 $\pm$ 5                  |
| 33       | PVD   | 3.5                 | -              | TiCN                        | -                           | 8 $\pm$ 1                   |
| 34       | PVD   | 6.0                 | TiN            | $(\text{AlCr})_2\text{O}_3$ | -                           | 30 $\pm$ 2                  |
| 35       | PVD   | 6.5                 | TiN            | TiCN                        | $(\text{AlCr})_2\text{O}_3$ | 34 $\pm$ 3                  |
| 36       | PVD   | 7.0                 | TiN            | $(\text{AlV})_2\text{O}_3$  | -                           | 32 $\pm$ 3                  |
| 37       | PVD   | 7.5                 | TiN            | TiCN                        | $(\text{AlV})_2\text{O}_3$  | 36 $\pm$ 3                  |

5 **Example F)** Turning of forging steel \_AISI 4137H (DIN 1.7225)

Cutting speed:  $v_c = 100 \text{ m/min}$

Feed rate:  $f_z = 0.80 \text{ mm/tooth}$

Depth of cut:  $d_c = 5 - 15 \text{ mm}$

Process: continuous turning of outer diameter

10 Insert type: Cemented carbide, 6% non-enriched,  
ISO TNMG 330924.

Sharp cutting edges for PVD coating,  
chamfered and honed to a slight  $50 \mu\text{m}$   
radius before CVD coating.

15 Table 6)

| Exp. Nr. | Type | d [ $\mu\text{m}$ ] | Coating layers |                             |                             | Tool life [pieces per edge] |
|----------|------|---------------------|----------------|-----------------------------|-----------------------------|-----------------------------|
| 32       | CVD  | 8.0                 | TiC            | TiCN                        | TiN                         | 7 $\pm$ 2                   |
| 33       | PVD  | 3.5                 | -              | TiCN                        | -                           | 3 $\pm$ 1                   |
| 34       | PVD  | 6.0                 | TiN            | $(\text{AlCr})_2\text{O}_3$ | -                           | 14 $\pm$ 1                  |
| 35       | PVD  | 6.5                 | TiN            | TiCN                        | $(\text{AlCr})_2\text{O}_3$ | 15 $\pm$ 2                  |
| 36       | PVD  | 7.0                 | TiN            | $(\text{AlV})_2\text{O}_3$  | -                           | 14 $\pm$ 2                  |
| 37       | PVD  | 7.5                 | TiN            | TiCN                        | $(\text{AlV})_2\text{O}_3$  | 16 $\pm$ 3                  |

It could be demonstrated by examples A to F that oxidic coatings can be beneficially applied on sharp edged tools by PVD coating processes. A sharp edge is desirable because it leads to lower cutting forces, reduced tool-tip temperatures  
20 to a finer workpiece surface finish and to an essential improvement of tool life.

**P A T E N T   C L A I M S**

1. A cutting tool comprising
  - a cemented carbide, CBN, cermet or ceramic sintered body having a cutting edge with an edge radius  $R_e$ , a flank and a rake face, and
  - a single layer or multilayer PVD coating covering at least a portion of the surface of the sintered body and comprising at least one oxidic layer, characterized in that
- 5 the edge radius  $R_e$  is smaller than 40  $\mu\text{m}$ , preferably smaller than or equal to 30  $\mu\text{m}$ .
2. Cutting tool according to claim 1, characterized in that the PVD coating is free of thermal cracks.
3. Cutting tool according to claim 1 or claim 2,
- 15 characterized in that the PVD coating is free of halogenides.
4. Cutting tool according to one of claims 1 to 3, characterized in that the oxidic layer comprises an electrically insulating oxide comprising at least one
- 20 element selected from the group of transition metals of the IV, V, VI group of the periodic system and Al, Si, Fe, Ni, Co, Y, La.
5. Cutting tool according to one of claims 1 to 4, characterized in that the oxidic layer comprises a
- 25 cubic or a hexagonal crystal structure.
6. Cutting tool according to one of claims 1 to 5, characterized in that the oxidic layer comprises an  $(\text{Al}_{1-x}\text{Cr}_x)_2\text{O}_3$  compound.

7. Cutting tool according to one of claims 1 to 6, characterized in that the oxidic layer comprises a corundum type structure.
8. Cutting tool according to claim 7, characterized in that the corundum type structure is corundum or a multiple oxide having the following composition:  
 $(Me_{1-x}Me_2)_2O_3$ , with  $0.2 \leq x \leq 0.98$ ,  
wherein Me1 and Me2 are different elements from the group Al, Cr, Fe, Li, Mg, Mn, Nb, Ti, Sb, V.
9. Cutting tool according to claim 7 or claim 8, characterized in that the corundum type structure is  $(AlCr)_2O_3$  or  $(AlV)_2O_3$ .
10. Cutting tool according to one of claims 1 to 9, characterized in that the PVD coating is a multilayer.
11. Cutting tool according to claim 10 or claim 11, characterized in that the oxidic layer comprises films of different oxides.
12. Cutting tool according to claim 11, characterized in that the PVD coating comprises
- an adhesion layer situated directly on the sintered body surface and/or
  - at least one hard wear protective layer situated between the sintered body and the oxidic layer, or between two or more consecutive oxidic layers and/or is the outermost of the PVD coating layers,
- wherein the adhesion layer and the hard protective layer, respectively, preferably comprises at least one element of the group of a transition metal from group

IV, V, VI of the periodic system of the elements and of Al, Si, Fe, Ni, Co, Y, La.

13. Cutting tool according to claim 12, characterized in that said at least one element of the wear protective layer is comprised in a compound together with N, C, O, B or with a mixture thereof, wherein N, C and CN are preferred.
14. Cutting tool according to claim 12 or 13, characterized in that at least one wear protective layer comprises at least one composition-segregated film.
15. Cutting tool according to one of claims 12 to 14, characterized in that said at least one element of the adhesion layer is comprised in a compound together with N, C, O or a mixture thereof, wherein N and O is preferred.
16. Cutting tool according to one of claims 12 to 15, characterized in that the adhesion layer has a thickness of 0.1 to 1.5  $\mu\text{m}$ .
17. Cutting tool according to one of claims 12 to 16, characterized in that the adhesion layer comprises a thin metallic layer situated directly on the sintered body surface.
18. Cutting tool according to one of claims 1 to 17, characterized in that the overall coating thickness is 2 to 30  $\mu\text{m}$ , preferably 3 to 10  $\mu\text{m}$ .

19. Cutting tool according to one of claims 1 to 18,  
characterized in that the sintered body is not binder-  
enriched.
20. Cutting tool according to one of claims 1 to 18,  
5 characterized in that the sintered body is binder-  
enriched.
21. Cutting tool according to one of claims 1 to 20,  
characterized in that the coating thickness of the  
flank face is different from the coating thickness of  
10 the rake face.
22. Cutting tool according to claim 21, characterized in  
that the tool is a milling tool and that  
$$Q_{R/F} = d_{\text{Rake}} / d_{\text{Flank}} < 1$$
  
applies, wherein  $d_{\text{Rake}}$  is the overall coating thickness  
15 on the rake face and  $d_{\text{Flank}}$  is the overall coating  
thickness on the flank face.
23. Cutting tool according to claim 21, characterized in  
that the tool is a turning tool and that  
$$Q_{R/F} = d_{\text{Rake}} / d_{\text{Flank}} > 1,$$
  
20 applies, wherein  $d_{\text{Rake}}$  is the overall coating thickness  
on the rake face and  $d_{\text{Flank}}$  is the overall coating  
thickness on the flank face.
24. Cutting tool according to one of claims 1 to 21,  
characterized in that the tool comprises or is an  
25 indexable insert.

25. Cutting tool according to one of claims 1 to 24,  
characterized in that the tool is a tool for at least  
one of the following working materials: metal,  
nonferrous metal, ferrous metal, cast iron.
- 5 26. Cutting tool according to one of claims 12 to 17,  
characterized in that the tool is a gear cutting tool  
or a hob or a shank type tool, having the oxidic layer  
as the outermost layer of the coating system.
- 10 27. Cutting tool according to claim 26, characterized in  
that the wear protective layer is a TiN, TiC or TiCN, a  
TiAlN or TiAlCN, an AlCrN or AlCrCN type layer, and is  
situated between the sintered body and the oxidic  
layer.