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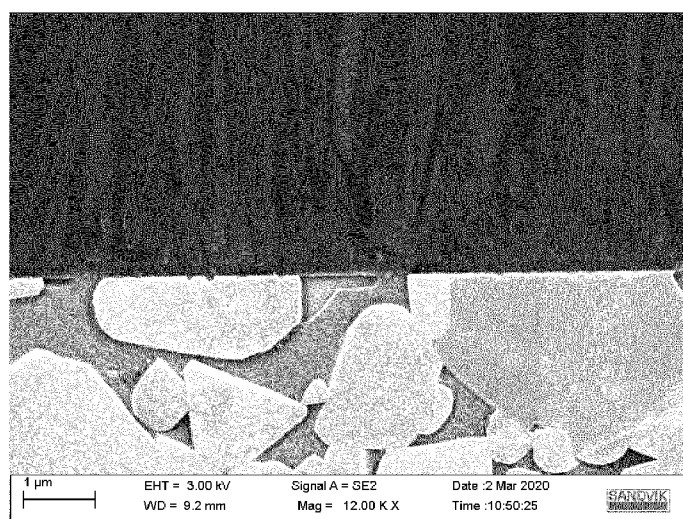


Fig. 1.

(57) Abstract: The present invention relates to a coated cutting tool. The cutting tool is CVD coated and the substrate is a cemented carbide wherein the metallic binder in the cemented carbide comprises Ni. The CVD coating comprises an inner layer of TiN and a subsequent layer of TiCN.



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A COATED CUTTING TOOL

TECHNICAL FIELD

The present invention relates to a coated cutting tool comprising a substrate and a coating, wherein the substrate is a cemented carbide wherein the metallic binder in
5 the cemented carbide comprises Ni. The coating is a CVD coating comprising an inner layer of TiN and a layer of TiCN.

BACKGROUND

The market of cutting tools for chip forming metal cutting operations is dominated by CVD (Chemical Vapor Deposition) and PVD (Physical Vapor Deposition) coated
10 cemented carbides wherein the cemented carbide is usually made of WC in a metallic binder of Co. Alternative metallic binders without Co or reduced amount of Co are being developed but are still rare or non-existing in the products on the market. Not only the production of the cemented carbide itself, but also the coating of the cemented carbide is demanding, especially during chemical vapor deposition
15 which is performed using reactive gases at high temperature, since interactions occur between the gas phase and the cemented carbide.

Among the alternative metallic binders Ni is a promising candidate: an element on the side of Co in the periodic table. Ni shows a high reactivity with Ti and a high amount of Ni in the cemented carbide causes problems in chemical vapor deposition
20 of a Ti-containing coating since intermetallic phases such as Ni₃Ti forms at the interface between the cemented carbide and the coating and in the coating. Intermetallic phases such as Ni₃Ti at the interface or in the inner part of the Ti-containing coating negatively influence the wear resistance of a coating subsequently deposited on the Ti-containing coating.

25 The problem of the formation of Ni₃Ti during deposition of a TiN coating on Ni metal substrates is analyzed in "Chemical vapor deposition of TiN on transition metal substrates" by L. von Fieandt et al, Surface and Coatings Technology 334 (2018) 373-383. It was concluded that the formation of Ni₃Ti could be reduced by an excess of N₂ partial pressure and low H₂ partial pressure during the CVD process.

It is an object of the present invention to provide a coated cutting tool for metal cutting with a Ni-containing cemented carbide substrate and with a high-performance wear resistant CVD coating. It is a further object to provide a wear resistant coating comprising a TiN layer, a TiCN layer and a 001 oriented $\alpha\text{-Al}_2\text{O}_3$ on a Ni containing cemented carbide substrate, especially a substrate containing a metallic binder with more than 60 wt% Ni.

DESCRIPTION OF THE INVENTION

At least one of the above-mentioned objects is achieved by a cutting tool according to claim 1. Preferred embodiments are disclosed in the dependent claims.

- 10 The present invention relates to a coated cutting tool comprising a substrate of cemented carbide and a coating, wherein the cemented carbide composed of hard constituents in a metallic binder and wherein said metallic binder comprises 55 to 80 mol% Ni and 10-35 mol% Co, 4-15 mol% W and wherein the coating comprises in order from the substrate an inner TiN layer and a TiCN layer, wherein the C-activity (carbon activity) relative to graphite in the metallic binder is lower than 0.15 and the average d electron value of the metallic binder is 7.0-7.43 wherein an interface between the substrate and the inner TiN layer is free of Ti-containing intermetallic phase.

- It was surprisingly found that a high quality of TiN and TiCN can be deposited on a cemented carbide substrate with a high Ni content in the metallic binder when the average d-electron value in the metallic binder is 7.0-7.43 and the C-activity relative to graphite is below 0.15. Coated cutting tools according to the present invention have surprisingly shown fewer pores at the inner part of the coating and this is promising for a wear resistant coating aimed for metal cutting applications. The inner TiN and the TiCN layer show improved properties relating to the formation of intermetallic phases, pores and disturbances relating to the orientation of the layer and subsequently deposited layers. Technical effects can be increased flank wear resistance and/or increased flaking resistance and/or increased crater wear resistance in metal cutting operations of for example steel.

The composition of the metallic binder in the cemented carbide have an impact on the quality of a layer deposited by CVD thereon, at least if a Ti-containing layer is to be deposited. TiN is a very common initial layer in cutting tool coatings. Without being bound to any theory the inventors have drawn the conclusion that during a CVD deposition of a TiN layer, N₂-molecules are believed to dissociate into N-atoms/N-radicals before they can react and form TiN. However, Ni in the surface increase the recombination rate of N₂ from N-atoms/radicals and thus passivates the N and prevents dissociation of N-atoms/radicals on the surface. Without N-atoms/radicals no TiN can form. Instead Ti might react with Ni forming NiTi₃ as described above. The reactivity of Ni in the metallic binder is influenced by the composition of the metallic binder. Further, it has been found that the number of d-electrons and the C-activity in the metallic binder is important.

The average number of d-electrons of the metallic binder is not only set by the components Co, Ni and/or Fe, it is also influenced by other metallic elements present in the alloy that is the metallic binder. For example, the W content have a relatively high impact on the average number of d-electrons in the metallic binder. The W content in the binder is highly influenced by the C content such that an excess of C results in lower W content and a lower C results in a higher W content in the metallic binder.

The C-activity is a thermodynamic measure of how easy carbon can react with other elements. It is expressed as a dimensionless quantity between 0 and 1. It is related to the concentration but takes properly into account all physical interactions that limit the whole amount of carbon to react. The definition of carbon activity is

$$\text{C-activity} = \exp((\mu - \mu_{\text{graf}})/RT)$$

where μ is the chemical potential of carbon in the material, μ_{graf} is the chemical potential of carbon in pure graphite, R is the gas constant and T is the temperature. The carbon activity is a good measure of the position in the phase diagram, an activity close to 1 means that the cemented carbide is close to having free carbon in the microstructure, whereas a low value, close to 0.1, means that the cemented carbide is prone to having eta phase (Me₆C and Me₁₂C phases) in the microstructure.

Cemented carbide is herein meant a material comprising hard constituents distributed in a continuous metallic binder phase. This kind of material has properties combining a high hardness from the hard constituents with a high toughness from the metallic binder phase and is suitable as a substrate material for metal cutting tools. By "cemented carbide" is herein meant a material that comprises at least 50 wt% WC, possibly other hard constituents common in the art of making cemented carbides and a metallic binder.

The metallic binder of the cemented carbide can comprise elements that are dissolved in the metallic binder during sintering, such as W and C originating from the WC. Depending on what types of hard constituents that are present, also other elements can be dissolved in the binder.

By "cutting tool" is herein meant a cutting tool for metal cutting such as an insert, an end mill or a drill. The application areas can be turning, milling or drilling.

By intermetallic phase is herein meant a metal alloy of two or more metallic elements. By Ti-containing intermetallic phase one of these metallic elements is Ti. In one embodiment of the present invention the Ti-containing intermetallic phase is Ni_3Ti .

Presence of Ti-containing intermetallic phase in the interphase and/or in the part of the TiN layer adjacent to the substrate influences the growth of the TiN layer and also of subsequent layers. The intermetallic phases disturb a columnar growth and pores are commonly found in combination with the intermetallic phases. Normally the TiN and the subsequent TiCN grow with columnar grains, and in an analyze in SEM of a sample with intermetallic phases present, a disturbed growth is found.

In one embodiment of the present invention the C-activity in the metallic binder is 0.095-0.12.

In one embodiment of the present invention the interface between the substrate and the coating is free of Ti- and Ni-containing intermetallic phase..

In one embodiment of the present invention the average d electron value is 7.20-7.43.

In one embodiment of the present invention the average d electron value is 7.30-7.43.

In one embodiment of the present invention the metallic binder comprises 65 to 80 mol% Ni and 10-25 mol% Co, 8-13 mol% W.

- 5 In one embodiment of the present invention the metallic binder content in the cemented carbide is 3-20 wt%, preferably 5-15 wt%, most preferably 7-12 wt%.

In one embodiment of the present invention the total thickness of the coating is 2-20 μm . The coating is preferably a CVD coating.

- 10 In one embodiment of the present invention the thickness of the TiN layer is 0.1-1 μm , preferably deposited on the cemented carbide substrate.

In one embodiment of the present invention the thickness of the TiCN layer is 6-12 μm .

- 15 In one embodiment of the present invention the wherein the coating comprises an $\alpha\text{-Al}_2\text{O}_3$ layer located between the TiCN layer and an outermost surface of the coated cutting tool.

In one embodiment of the present invention the thickness of the Al_2O_3 layer located between the TiCN layer and an outermost surface of the coated cutting tool is 4-8 μm .

- 20 In one embodiment of the present invention the $\alpha\text{-Al}_2\text{O}_3$ layer exhibits a texture coefficient $\text{TC}(h\ k\ l)$, as measured by X-ray diffraction using $\text{CuK}\alpha$ radiation and θ - 2θ scan, defined according to Harris formula

$$\text{TC}(hkl) = \frac{I(hkl)}{I_0(hkl)} \left[\frac{1}{n} \sum_{n=1}^n \frac{I(hkl)}{I_0(hkl)} \right]^{-1} \quad (1)$$

where $I(h\ k\ l)$ is the measured intensity (integrated area) of the $(h\ k\ l)$ reflection,

- 25 $I_0(h\ k\ l)$ is the standard intensity according to ICDD's PDF-card No. 00-010-0173, n is the number of reflections used in the calculation, and where the $(h\ k\ l)$ reflections

used are (1 0 4), (1 1 0), (1 1 3), (024), (1 1 6), (2 1 4), (3 0 0) and (0 0 12), wherein $TC(0\ 0\ 12) \geq 6$, preferably ≥ 7 .

In one embodiment of the present invention the coating further comprises one or more layers selected from TiN, TiCN, AlTiN, ZrCN, TiB₂, Al₂O₃, or multilayers comprising α -Al₂O₃ and/or κ -Al₂O₃.

In one embodiment of the present invention the cemented carbide substrate comprises eta phase. By eta phase is herein meant carbides selected from Me₆C and Me₁₂C where Me is selected from W and one or more of the binder phase metals. Common carbides are W₆Co₆C, W₃Co₃C, W₆Ni₆C, W₃Ni₃C, W₆Fe₆C, W₃Fe₃C.

In one embodiment the cemented carbide substrate comprises carbides, carbonitrides or nitrides of one or more of Ti, Ta, Nb, Cr, Mo, Zr or V.

BRIEF DESCRIPTION OF DRAWINGS

Embodiments of the invention and also references will be described with reference to the accompanying drawings, wherein:

Figure 1 is a cross-sectional SEM micrograph showing the substrate coating interface of a coated cutting tool, NC60e with the coating of CVD process 1 (invention),

Figure 2 is a cross-sectional SEM micrograph showing the substrate coating interface of a coated cutting tool, NC70e with the coating of CVD process 1 (invention),

Figure 3 is a cross-sectional SEM micrograph showing the substrate coating interface of a coated cutting tool, NC70e with the coating of CVD process 2 (invention),

Figure 4 is a cross-sectional SEM micrograph showing the substrate coating interface of a coated cutting tool, NC80e with the coating of CVD process 1 (reference),

Figure 5 is a cross-sectional SEM micrograph showing the substrate coating interface of a coated cutting tool, NC80e with the coating of CVD process 2 (invention),

Figure 6 is a cross-sectional SEM micrograph showing the substrate coating interface of a coated cutting tool, N100e with the coating of CVD process 1 (reference),

Figure 7 is top view SEM micrograph showing the outer surface of a coated cutting tool, substrate NC70e with the coating of CVD process 2 (invention),

Figure 8 is top view SEM micrograph showing the outer surface of a coated cutting tool, substrate N100e with the coating of CVD process 2 (reference).

METHODS

The cemented carbide substrate of the invention can be made according to the following steps:

- providing powders forming or being hard constituents such as W, Ta, Cr, C, WC, TiC, etc.
- providing powders forming metallic binder such as Co, Ni
- providing milling liquid
- milling, drying, pressing and sintering the powders into cemented carbide substrates.

During sintering oxygen will react with carbon and leave the substrate as CO or CO₂. Exactly how much carbon that is lost during sintering depends on the raw material and production techniques used and it is up to the person skilled in the art to adjust the amount of each component so that the aimed sintered material is achieved.

The C content in the cemented carbide was analyzed with carbon combustion analysis in a LECO 844 Series instrument. The C content in the cemented carbide is measured in the sintered substrate. Some of the C that is mixed in the powder during the production of the cemented carbide is consumed during sintering, some carbon can dissolve in the metallic binder and some carbon might form carbides.

The present invention is related to the composition of the metallic binder, and since it is expensive and complicated to produce samples the composition was calculated with a software called Thermo-Calc. The composition of the metallic binder can alternatively be measured with XRF (X-ray fluorescence).

5 Thermo-Calc is a software package that is world-wide used by material scientists, researchers and industry in the field of materials engineering for development and production of both materials and components. The development of the Thermo-Calc software was started already in the mid 70's at the department for physical metallurgy at the Royal Institute of Technology in Stockholm, Sweden, and in 1997
10 Thermo-Calc Software AB was founded. More information can be found at: www.thermocalc.com. Thermo-Calc provides for example thermodynamic calculations of the amounts of phases and their compositions and the phase diagrams (binary, ternary and multi-component).

The calculations made with Thermo-Calc are based on thermodynamic data which
15 is supplied in high-quality databases for various purposes that include many different materials. The databases are produced by experts through assessment and systematic evaluation of experimental and theoretical data, following the well-established so-called CALPHAD technique. The databases provided by Thermo-Calc Software AB are validated against experimental data to evaluate their accuracy
20 in the calculated predictions.

The database used herein for the Thermo-Calc calculations was "TCFE7" commercially available from Thermo-Calc Software AB. TCFE7 is a thermodynamic database for different kinds of steels, Fe-based alloys (stainless steels, high-speed steels, tool steels, HSLA steels, cast iron, corrosion-resistant high strength steels
25 and more) and cemented carbides. The TCFE7 database is validated against experimental data and shows accurate predictions, among others, for cemented carbides, especially in predicting correct phases and fractions, phase compositions and solid/liquid equilibrium temperatures.

The composition of the metallic binder in the present invention was determined
30 using Thermo-Calc software which is further described in [J.-O. Andersson, T.

Helander, L. Hoglund, P. Shi, and B. Sundman, Thermo-Calc & DICTRA, computational tools for material science, Calphad, 2002:26(2):273312].

The Thermo-Calc calculations of the present invention was made with the criterions: atmospheric pressure, a temperature of 1000 °C, one mole of substance, weighed
5 in compositions of Ni, Fe, and Co with the addition of milled in Co, C level from chemical analysis and balance of W.

When the composition of the metallic binder, in mol%, is known the average number of d electrons is calculated as follows: The d-electrons are counted as the number of electrons in the highest d-orbital per element, e.g. 6 for Fe, 7 for Co, 8 for Ni, 0
10 for C, and 4 for W.

The coatings in the examples below were deposited in a radial Ionbond Bernex TM type CVD equipment 530 size capable of housing 10000 half-inch size cutting inserts.

In order to investigate the texture of the layer(s) X-ray diffraction was conducted on
15 the flank face and the rake face of cutting tool inserts using a Xpert-Pro diffractometer system equipped with a X'Celerator RTMS detector type. The coated cutting tool inserts were mounted in sample holders to ensure that the surface of the cutting tool inserts was parallel to the reference surface of the sample holder and also that the cutting tool surface was at appropriate height. Cu-K α radiation was
20 used for the measurements, with a voltage of 45 kV and a current of 40 mA. A 0.02 radian soller slit and a 0.25 degree divergence slit were used for the incident beam path. For the diffracted beam a 0.25 degree anti-scatter slit and 0.02 radian soller slit were used. The Beta-filter Nickel had a thickness of 0.020 mm. The diffracted intensity from the coated cutting tool was measured in the range 15° to 140° 2 θ , i.e.
25 over an incident angle θ range from 10 to 70°.

The data analysis, including background subtraction, Cu-K α_2 stripping and profile fitting of the data, was done using PANalytical's X'Pert HighScore Plus software. A general description of the fitting is made in the following. The output (integrated peak areas for the profile fitted curve) from this program was then used to calculate the
30 texture coefficients of the layer by comparing the ratio of the measured intensity

data to the standard intensity data according to a PDF-card of α -Al₂O₃, using the Harris formula (1) as disclosed above. Since the layer is finitely thick the relative intensities of a pair of peaks at different 2θ angles are different than they are for bulk samples, due to the differences in path length through the layer. Therefore, thin film
5 correction was applied to the extracted integrated peak area intensities for the profile fitted curve, taken into account also the linear absorption coefficient of layer, when calculating the TC values. Since possible further layers above the α -Al₂O₃ layer will affect the X-ray intensities entering the α -Al₂O₃ layer and exiting the whole coating, corrections need to be made for these as well, taken into account the linear
10 absorption coefficient for the respective compound in a layer. Alternatively, a further layer, such as TiN, above an alumina layer can be removed by a method that does not substantially influence the XRD measurement results, e.g. chemical etching.

In order to investigate the texture of the α -Al₂O₃ layer X-ray diffraction was conducted using CuK α radiation and texture coefficients TC (h k l) for different
15 growth directions of the columnar grains of the α -Al₂O₃ layer were calculated according to Harris formula (1), where $I(h\ k\ l)$ = measured (integrated area) intensity of the (h k l) reflection, $I_0(h\ k\ l)$ = standard intensity according to ICDD's PDF-card no 00-010-0173, n = number of reflections to be used in the calculation. In this case the (h k l) reflections used are: (1 0 4), (1 1 0), (1 1 3), (0 2 4), (1 1 6), (2 1 4), (3 0 0)
20 and (0 0 12).

It is to be noted that peak overlap is a phenomenon that can occur in X-ray diffraction analysis of coatings comprising for example several crystalline layers and/or that are deposited on a substrate comprising crystalline phases, and this has to be considered and compensated for. An overlap of peaks from the α -Al₂O₃ layer with
25 peaks from the TiCN layer might influence measurement and needs to be considered. It is also to be noted that for example WC in the substrate can have diffraction peaks close to the relevant peaks of the present invention.

EXAMPLES

Exemplifying embodiments of the present invention will now be disclosed in more
30 detail and compared to reference embodiments. Coated cutting tools (inserts) were manufactured and analyzed.

Cemented carbide substrates of ISO-type SNUN120408 were manufactured. The cemented carbide substrates were manufactured with WC in a metallic binder, wherein the metallic binder content was about 10 wt%. The cemented carbide substrates were manufactured from a powder mixture. The powder mixture was milled, dried, pressed and sintered at 1450°C. WC/Co milling bodies were used during the milling and mixing step. The amount carbon in the powder was about 6.07 wt%, while the amount carbon as measured in chemical analysis of the sintered cemented carbide is presented in table 1A and 1B. The sintered cemented carbide comprised about 0.4 wt% Co originating mainly from the milling bodies that were worn during the milling step. No free graphite was visible in a SEM micrograph of a cross section of the cemented carbide substrates.

The C level of the substrates was measured with LECO carbon combustion. The compositions of the cemented carbide substrates are listed in wt% in table 1A, so called e-samples, and 1B, so called f-samples.

Table 1A. Summary of cemented carbide substrates, e-samples

Substrate	Ni [wt%]	Co [wt%]	C [wt%]	W [wt%]
NC50e	4.99	5.41	5.19	84.41
NC60e	5.99	4.41	5.23	84.37
NC70e	6.99	3.41	5.21	84.39
NC80e	7.99	2.41	5.22	84.38
NC90e	9.00	1.40	5.20	84.40
N100e	10.05	0.40	5.16	84.39

Table 1B. Summary of cemented carbide substrates, f-samples

Substrate	Ni [wt%]	Co [wt%]	C [wt%]	W [wt%]
NC50f	4.99	5.41	5.37	84.23
NC60f	5.99	4.41	5.35	84.25
NC70f	6.99	3.41	5.37	84.23
NC80f	7.99	2.41	5.37	84.23
NC90f	9.00	1.40	5.34	84.26
N100f	10.16	0.40	5.29	84.15

The composition of the metallic binder was calculated with Thermo-Calc using the following conditions: atmospheric pressure, a temperature of 1000 °C, one mole of substance, weighed in compositions of Ni, Fe, and Co with the addition of milled in Co, C level from chemical analysis and balance of W. The resulting binder compositions, excluding carbides, are listed in mol% in table 2A (e-samples) and 2B (f-samples).

To calculate the average number of d-electrons in the binder, the calculated composition of the metallic binder is used. The d-electrons are counted as the number of electrons in the highest d-orbital per element, e.g. 7 for Co, 8 for Ni, 0 for C, and 4 for W. The average number of d electrons in the binders are presented in table 2A and 2B.

To calculate the carbon activity of the cemented carbide, first the chemical composition must be known. In the present examples the C-activity calculation is based on the values presented in Tables 1A and 1B. In an unknown sample, this can be measured by means of e.g. XRF.

A Thermo-Calc calculation of the thermodynamic equilibrium is performed at, atmospheric pressure, a temperature of 1000 °C, one mole of substance, compositions of Ni, Fe, Co, and C from chemical analysis and balance of W. The carbon activity relative to graphite at this equilibrium is then extracted as an output parameter from Thermo-Calc, see Tables 2A and 2B.

Table 2A. Summary of metallic binder, e-samples

Substrate	Ni [mol%]	Co [mol%]	C [mol%]	W [mol%]	Average number of d electrons	C- activity
NC50e	42.75	45.85	0.18	11.22	7.08	0.113
NC60e	51.15	37.43	0.17	11.25	7.16	0.111
NC70e	59.67	28.84	0.17	11.31	7.25	0.108
NC80e	68.01	20.33	0.18	11.48	7.32	0.106
NC90e	76.22	11.76	0.19	11.83	7.39	0.102
N100e	84.08	3.28	0.21	12.43	7.45	0.098

Table 2B. Summary of metallic binder, f-samples

Substrate	Ni [mol%]	Co [mol%]	C [mol%]	W [mol%]	Average number of d electrons	C- activity
NC50f	44.83	48.41	0.47	6.30	7.23	0.390
NC60f	53.38	39.14	0.39	7.10	7.29	0.320
NC70f	64.30	27.92	0.38	7.40	7.39	0.429
NC80f	71.63	21.48	0.54	6.35	7.49	0.454
NC90f	79.59	12.37	0.46	7.58	7.54	0.334
N100f	87.05	3.41	0.41	9.12	7.57	0.240

- 5 CVD coatings were deposited on the cemented carbide compositions presented in Table 2A and Table 2B and a summary of the CVD coatings are given in Table 3. Prior to the coating deposition the rake faces were polished to remove the outermost metal from the surfaces, the flank face was left unpolished. The polishing was performed by mounting each of SNUN120408 samples in a black conductive
- 10 phenolic resin from AKASEL which were afterwards ground down about 1 mm and

then polished in two steps: rough polishing (9 μ m) and fine polishing (1 μ m) using a diamond slurry solution. After polishing the SNUN120408 sample were taken out from the black conductive phenolic resin and washed in ethanol before coating.

Table 3. Summary of CVD processes

CVD process	TiN- 1	TiN-2	TiN total [μ m]	TiCN [μ m]	bonding layer [μ m]	α -Al ₂ O ₃ [μ m]
Process CVD 1 (normal)	No	Yes	0.2	8.5	0.9	5.4
Process CVD 2 (modified)	Yes	Yes	0.7	10	0.9	5.2

5

Before starting the CVD deposition the CVD chamber was heated up to reach 885 °C. The pre-heating step was performed at 1000 mbar and in 100 vol% H₂ for both Process CVD 1 and Process CVD 2.

- 10 In the Process CVD 1 the substrates were first coated with an about 0.2-0.3 μ m thick TiN-layer at 885 °C, process TiN-2. In the Process CVD 2 two alternative depositions of TiN were performed: an initial step of TiN-1 followed by process TiN-2. The aim of the TiN-1 step is to prevent intermetallic phases such as Ni₃Ti from forming in the CVD coating and at the substrate-coating interface. During the TiN-1
- 15 deposition the N₂ partial pressure was high and the H₂ partial pressure was low, and HCl was added, as compared to the TiN-2 deposition step which was performed without HCl and with a 50/50 relation for the H₂/N₂ gasses. When the TiN-1 was deposited, the subsequent TiN-2 deposition time was adapted to reach a total TiN layer thickness of 0.7 μ m. The TiN-1 deposition was run for 150 minutes.
- 20 Thereafter an approximately 8 μ m TiCN layer was deposited by employing the well-known MTCVD technique using TiCl₄, CH₃CN, N₂, HCl and H₂ at 885 °C. The volume ratio of TiCl₄/CH₃CN in an initial part of the MTCVD deposition of the TiCN

layer was 6.6, followed by a period using a ratio of $\text{TiCl}_4/\text{CH}_3\text{CN}$ of 3.7. The details of the TiN and the TiCN deposition are shown in Table 4.

Table 4. MTCVD of TiN and TiCN

MT CVD of TiN and TiCN (885°C):	Pressure [mbar]	H ₂ [vol%]	N ₂ [vol%]	HCl [vol%]	TiCl ₄ [vol%]	CH ₃ CN [vol%]
TiN-1	1000	10.5	87.4	0.88	1.25	-
TiN-2	400	48.8	48.8	-	2.44	-
TiCN inner	55	59.0	37.6	-	2.95	0.45
TiCN outer	55	81.5	7.8	7.8	2.38	0.65

- 5 After the deposition of the TiCN outer layer the temperature was increased from 885°C to 1000°C in an atmosphere of 75 vol% H₂ and 25 vol% N₂ at 55 mbar for the Process CVD 1 After the deposition of the TiCN outer layer the temperature was increased from 885°C to 1000°C in an atmosphere of 100 vol% N₂ at 1000 mbar for the Process CVD 2.
- 10 A 1-2 µm thick bonding layer was deposited at 1000°C on top of the MTCVD TiCN layer by a process consisting of four separate reaction steps. First a HTCVD TiCN step using TiCl₄, CH₄, N₂, HCl and H₂ at 400 mbar, then a second step (TiCNO-1) using TiCl₄, CH₃CN, CO, N₂ and H₂ at 70 mbar, then a third step (TiCNO-2) using TiCl₄, CH₃CN, CO, N₂ and H₂ at 70 mbar and finally a fourth step (TiN-3) using TiCl₄, N₂ and H₂ at 70 mbar. Prior to the start of the subsequent Al₂O₃ nucleation, the bonding layer was oxidized for 4 minutes in a mixture of CO₂, CO, N₂ and H₂.
- 15

The details of the bonding layer deposition are shown in Table 5.

Table 5. Bonding layer deposition

Bonding layer	Pressure [mbar]	H ₂ [vol%]	N ₂ [vol%]	CH ₄ [vol%]	HCl [vol%]	CO [vol%]	TiCl ₄ [vol%]	CH ₃ CN [vol%]	CO ₂ [vol%]
HTCVD TiCN	400	67.9	25.5	3.4	1.7	-	1.55	-	-
TiCNO-1	70	83.7	12.0	-	1.2	1.2	1.5	0.40	-
TiCNO-2	70	63.1 - 61.1	31.5 - 30.6	-	-	1.6 - 4.6	3.15 - 3.06	0.65- 0.63	-
TiN-3	70	64.5	32.3	-	-	-	3.23	-	-
Oxidation	55	53.8	30	-	-	12.5	-	-	3.7

On top of the bonding layer an α -Al₂O₃ layer was deposited. All the α -Al₂O₃ layers were deposited at 1000°C and 55 mbar in two steps. The first step using 1.2 vol-% AlCl₃, 4.7 vol-% CO₂, 1.8 vol-% HCl and balance H₂ giving about 0.1 μ m α -Al₂O₃ and a second step as disclosed below giving a total α -Al₂O₃ layer thickness of about 5 μ m. The second step of the α -Al₂O₃ layer was deposited using 1.2 % AlCl₃, 4.7 % CO₂, 3.0 % HCl, 0.58 % H₂S and balance H₂.

XRD was used to analyse the texture coefficient (TC) values of the α -Al₂O₃ in accordance with the method as disclosed above. The layer thicknesses were analyzed in a Carl Zeiss AG -Supra 40SEM (Scanning Electron Microscope) type by studying a cross section of each coating at 12000x magnification and both the bonding layer and the initial TiN layer are included in the TiCN layer thickness, see Table 1. Both the polished rake face and the unpolished flank face were studied. The results from the XRD are presented in Table 6A and 6B.

Table 6A. XRD results (e-samples)

Sample	TC(0 0 12) of α -Al ₂ O ₃ flank face		TC(0 0 12) of α -Al ₂ O ₃ polished rake face	
	Process CVD 1	Process CVD 2	Process CVD 1	Process CVD 2
NC70e	6.10	Not analyzed	7.54	7.72
NC80e	7.01	Not analyzed	Not analyzed	7.75
NC90e	7.29	6.01	Not analyzed	7.61

Table 6B. XRD results (f-samples)

Sample	TC(0 0 12) of α -Al ₂ O ₃ flank face		TC(0 0 12) of α -Al ₂ O ₃ polished rake face	
	Process CVD 1	Process CVD 2	Process CVD 1	Process CVD 2
NC60f	6.80	Not analyzed	Not analyzed	Not analyzed
NC70f	6.63	Not analyzed	7.32	7.66
NC80f	5.95	Not analyzed	Not analyzed	7.00
NC90f	Not analyzed	Not analyzed	0.00	4.69

- 5 The coatings were also analyzed using SEM to study the presence of any Ni compounds such as intermetallic phases at the interface between substrate and the first TiN layer.

Top view images of the coated samples showed an unevenness or high surface roughness on the outer surface of the alumina. It was concluded that formation of intermetallic phases at the interface could be identified by studying the outer surface of the alumina in that an unexpectedly rough surface indicated intermetallic phases at the interface.

Cross section images were mainly focused at the interface between the substrate and the first TiN layer to determine if diffusion of binder elements (Ni compounds) had disturbed the growth of the coating. Occurrence of Ti-containing intermetallic phases (such as Ni₃Ti) depended on the binder composition.

The coating quality deposited in the Process CVD 1 and the Process CVD 2 on Ni rich binders was determined by analyzing both the outer surface and morphology of Al_2O_3 and also the interface between substrate and the first TiN layer. Unevenness of Al_2O_3 surface can be result from growth of coarse grains and correlates with the formation of intermetallic phases such as Ni_3Ti formed at the interface between the substrate and the coating. When the unevenness of the Al_2O_3 was difficult to determine the interface between the substrate and coating was analyzed to determine the coating quality. For this investigation, SEM was used at 12000X magnification and 3 parallel images were studied from 3 places on the sample approximately 10 μm apart along the substrate surface in order to detect presence of intermetallic phases. The results of the analyses are shown in Tables 7A and 7B.

Table 7A SEM analyse of e-samples

Sample	Ti-containing intermetallic phases identified in interface (cross section)		Visual unevenness or high surface roughness on outer surface of alumina (top view)	
	Process CVD 1	Process CVD 2	Process CVD 1	Process CVD 2
NC50e	No	Not analyzed	No	No
NC60e	No	Not analyzed	No	No
NC70e	No	No	No	No
NC80e	Yes	No	Yes	No
NC90e	Yes	Not analyzed	Yes	No
N100e	Yes	Not analyzed	Not analyzed	Yes

Table 7B SEM analyse of f-samples

Sample	Ti-containing intermetallic phases identified in interface (SEM cross section)		Visual unevenness or high surface roughness on outer surface of alumina (SEM top view)	
	Process CVD 1	Process CVD 2	Process CVD 1	Process CVD 2
NC50f	No	Not analyzed	No	No
NC60f	No	Not analyzed	No	No
NC70f	No	No	No	No
NC80f	Yes	Yes	Yes	Yes
NC90f	Yes	Not analyzed	Yes	Yes
N100f	Yes	Not analyzed	Yes	Yes

It is clear from the surface analysis and the cross section analysis that samples showing visual unevenness or high surface roughness on the outer surface of the alumina (top view) also showed Ti-containing intermetallic phases in the interface (cross section). It is unexpected that no Ti-containing intermetallic phases or disturbing pores appears at the interface of the CVD coating when the C-activity is low, lower than 0.15, and the average number of d electrons are 7.0-7.43, see Table 8.

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Table 8 Summary of results

Substrate partial name	e-samples		f-samples	
	d-electrons	C-activity	d-electrons	C-activity
NC50	7.08*	0.113	7.23*	0.390
NC60	7.16*	0.111	7.29*	0.320
NC70	7.25*	0.108	7.39**	0.429
NC80	7.32**	0.106	7.49**	0.454
NC90	7.39**	0.102	7.54***	0.334
N100	7.45***	0.098	7.57***	0.240

* No Ti-containing intermetallic phases present at interface

** CVD process 1: Ti-containing intermetallic phases at interface, CVD process 2:
no Ti-containing intermetallic phases at interface

5 *** Ti-containing intermetallic phases at interface

While the invention has been described in connection with various exemplary
embodiments, it is to be understood that the invention is not to be limited to the
disclosed exemplary embodiments; on the contrary, it is intended to cover various
10 modifications and equivalent arrangements within the appended claims.

CLAIMS

1. A coated cutting tool comprising a substrate of cemented carbide and a coating, wherein the cemented carbide composed of hard constituents in a metallic binder and wherein said metallic binder comprises 55 to 80 mol% Ni and 10-35 mol% Co, 4-15 mol% W and wherein the coating comprises in order from the substrate an inner TiN layer and a TiCN layer, wherein the C-activity relative to graphite in the metallic binder is lower than 0.15 and the average d electron value of the metallic binder is 7.00-7.43 characterized in that an interface between the substrate and the inner TiN layer is free of Ti-containing intermetallic phase.
2. The coated cutting tool of claim 1 wherein the C-activity in the metallic binder is 0.095-0.120.
3. The coated cutting tool of claim 1 or 2 wherein the interface between the substrate and the inner TiN layer is free of Ti- and Ni-containing intermetallic phase .
4. The coated cutting tool of any of the preceding claims wherein the average d electron value is 7.20-7.43.
5. The coated cutting tool of any of the preceding claims wherein the average d electron value is 7.30-7.43.
6. The coated cutting tool of any of the preceding claims wherein the metallic binder comprises 65 to 80 mol% Ni and 10-25 mol% Co, 8-13 mol% W.
7. The coated cutting tool of any of the preceding claims, wherein the metallic binder content in the cemented carbide is 3-20 wt%, preferably 5-15 wt%, most preferably 7-12 wt%.
8. The coated cutting tool of any of the preceding claims, wherein the total thickness of the coating is 2-20 μm .

9. The coated cutting tool of any of the preceding claims, wherein the coating is a CVD coating.
10. The coated cutting tool of any of the preceding claims, wherein the thickness of the TiN layer is 0.1-1 μm , preferably deposited on the cemented carbide substrate.
11. The coated cutting tool of any of the preceding claims, wherein the thickness of the TiCN layer is 6-12 μm .
12. The coated cutting tool of any of the preceding claims, wherein the coating comprises an $\alpha\text{-Al}_2\text{O}_3$ layer located between the TiCN layer and an outermost surface of the coated cutting tool.
13. The coated cutting tool of any of the preceding claims, wherein the thickness of the $\alpha\text{-Al}_2\text{O}_3$ layer located between the TiCN layer and an outermost surface of the coated cutting tool is 4-8 μm .
14. The coated cutting tool of any of the preceding claims, wherein said $\alpha\text{-Al}_2\text{O}_3$ layer exhibits a texture coefficient $TC(h\ k\ l)$, as measured by X-ray diffraction using $\text{CuK}\alpha$ radiation and θ - 2θ scan, defined according to Harris formula

$$TC(hkl) = \frac{I(hkl)}{I_0(hkl)} \left[\frac{1}{n} \sum_{n=1}^n \frac{I(hkl)}{I_0(hkl)} \right]^{-1}$$

where $I(h\ k\ l)$ is the measured intensity (integrated area) of the $(h\ k\ l)$ reflection, $I_0(h\ k\ l)$ is the standard intensity according to ICDD's PDF-card No. 00-010-0173, n is the number of reflections used in the calculation, and where the $(h\ k\ l)$ reflections used are $(1\ 0\ 4)$, $(1\ 1\ 0)$, $(1\ 1\ 3)$, $(0\ 2\ 4)$, $(1\ 1\ 6)$, $(2\ 1\ 4)$, $(3\ 0\ 0)$ and $(0\ 0\ 12)$, wherein $TC(0\ 0\ 12) \geq 6$, preferably ≥ 7 .

15. The coated cutting tool of any of the preceding claims, wherein the CVD coating further comprises one or more layers selected from TiN, TiCN, AlTiN, ZrCN, TiB_2 , Al_2O_3 , or multilayers comprising $\alpha\text{-Al}_2\text{O}_3$ and/or $\kappa\text{-Al}_2\text{O}_3$.

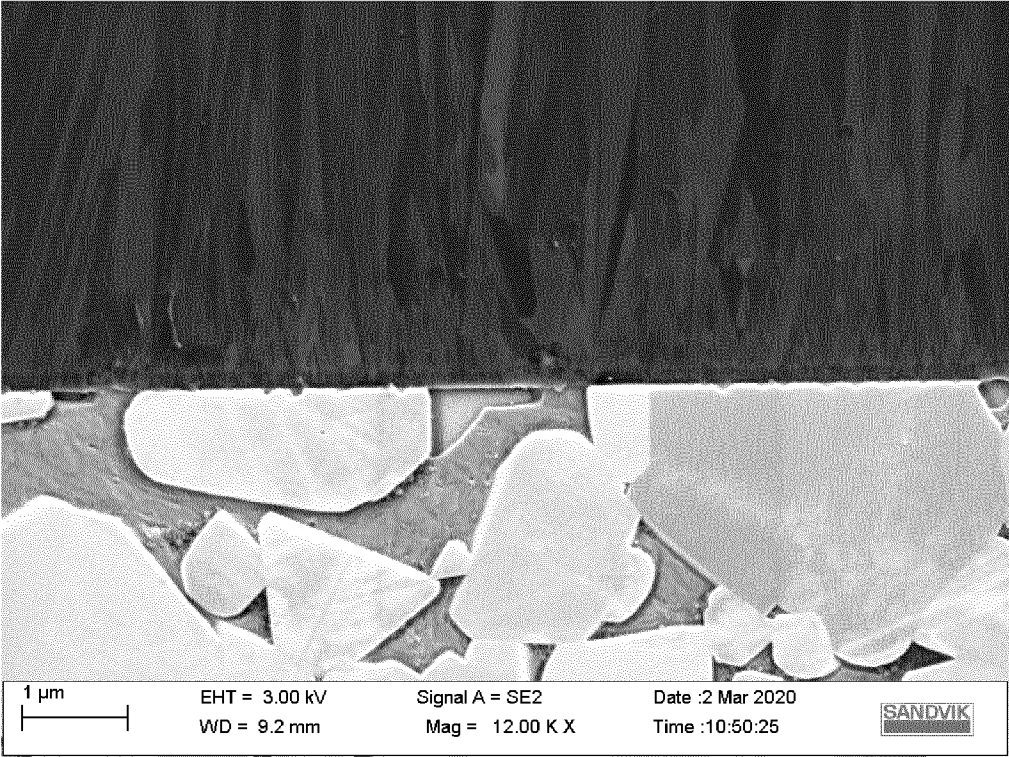


Fig. 1.

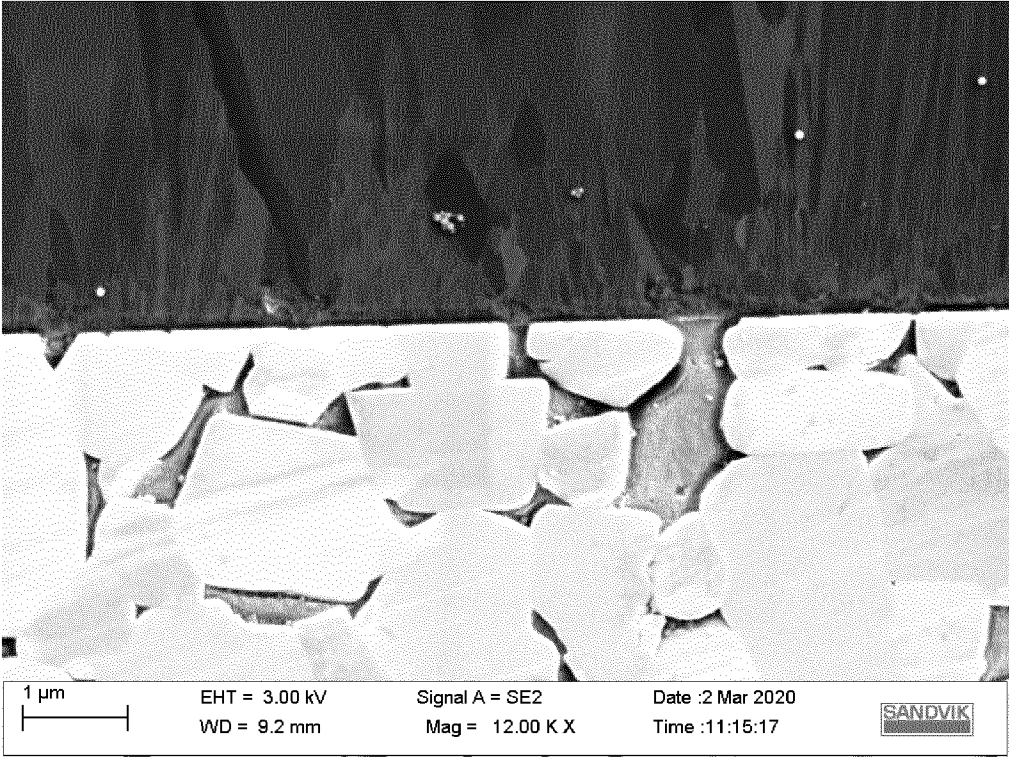


Fig. 2.

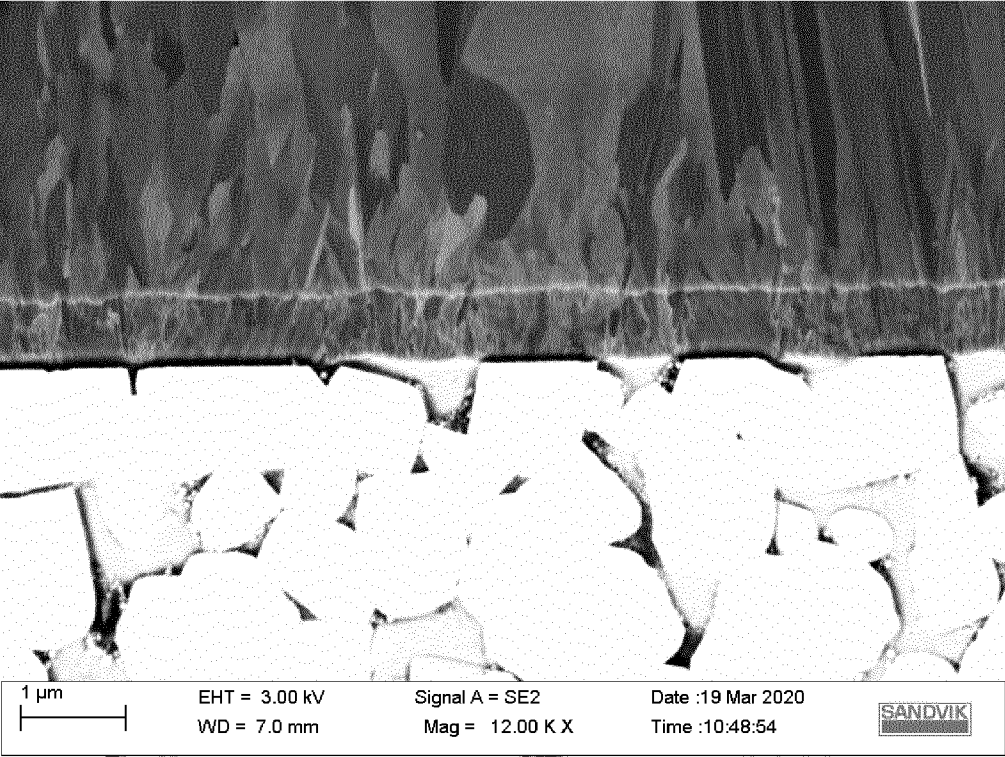


Fig. 3.

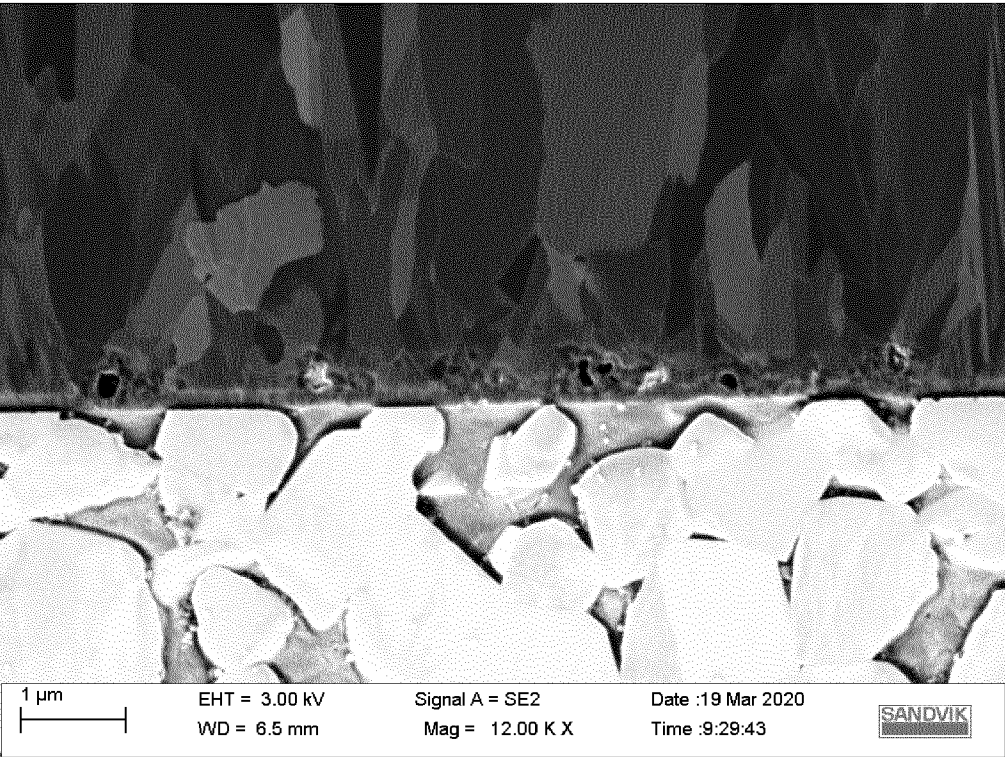


Fig. 4

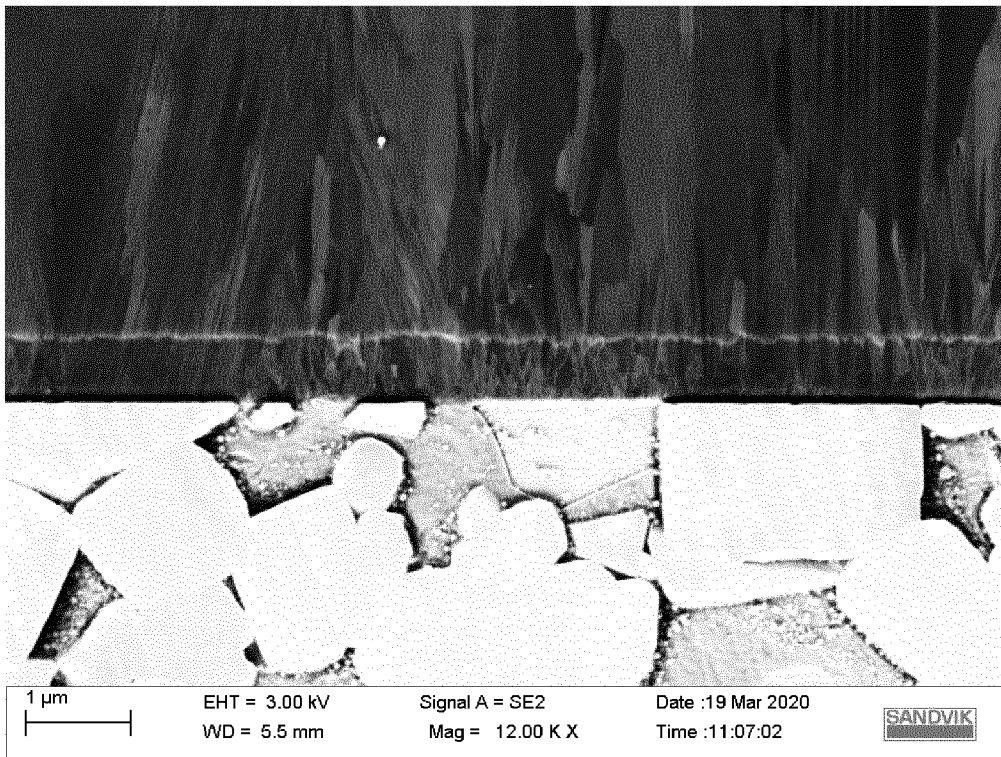


Fig. 5.

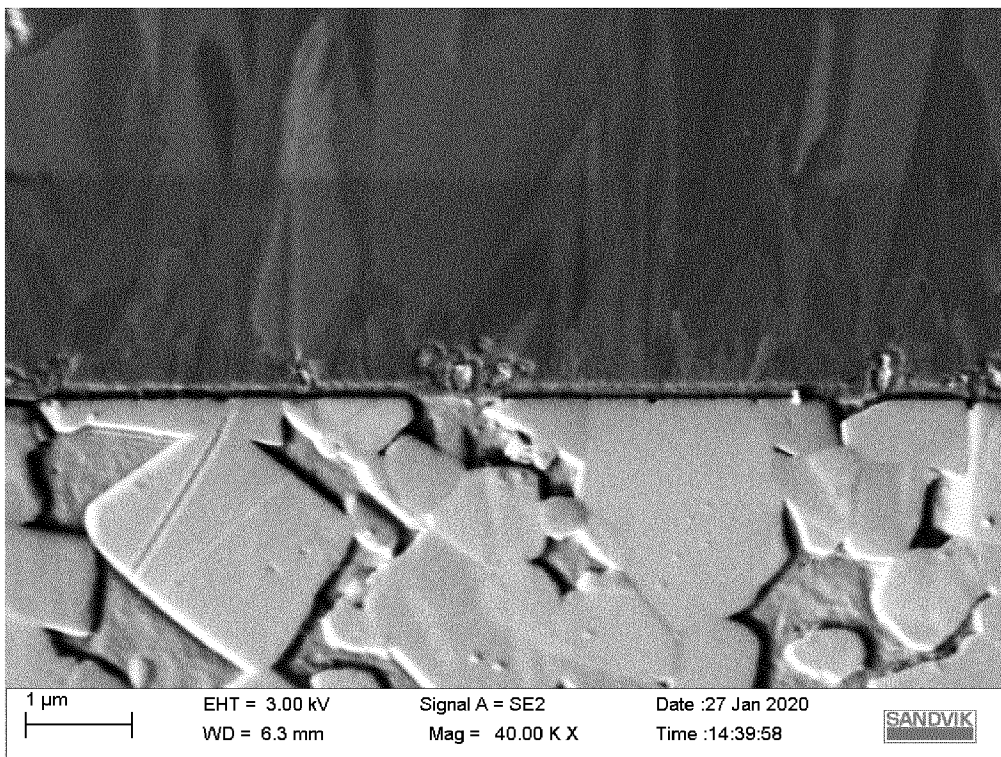


Fig. 6.

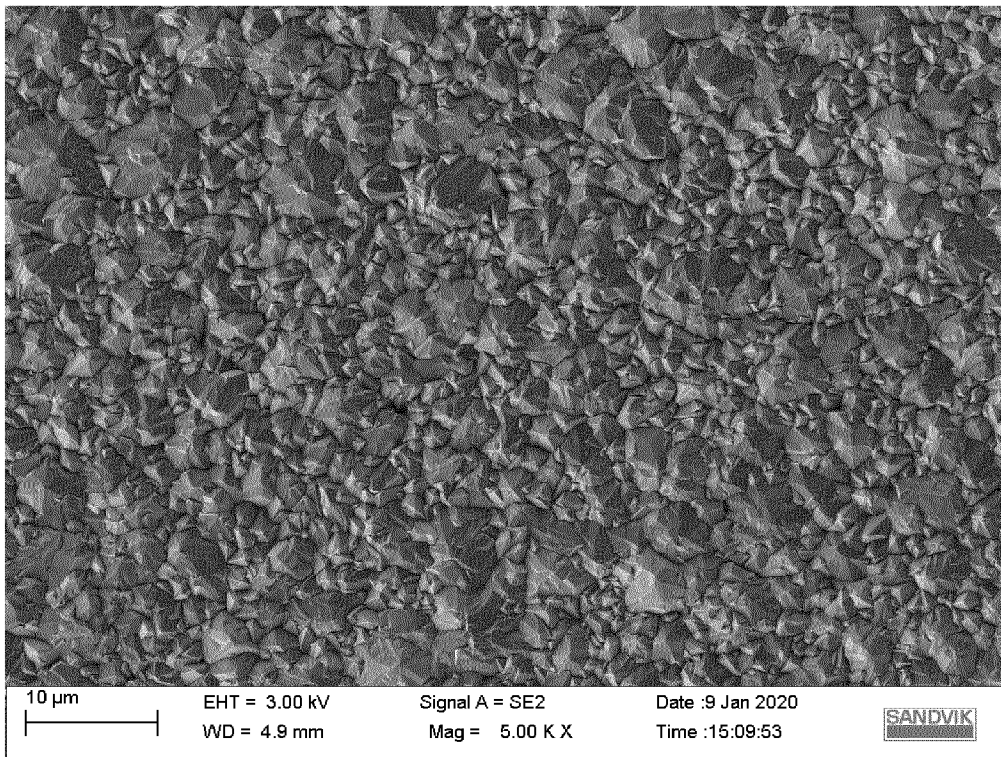


Fig. 7

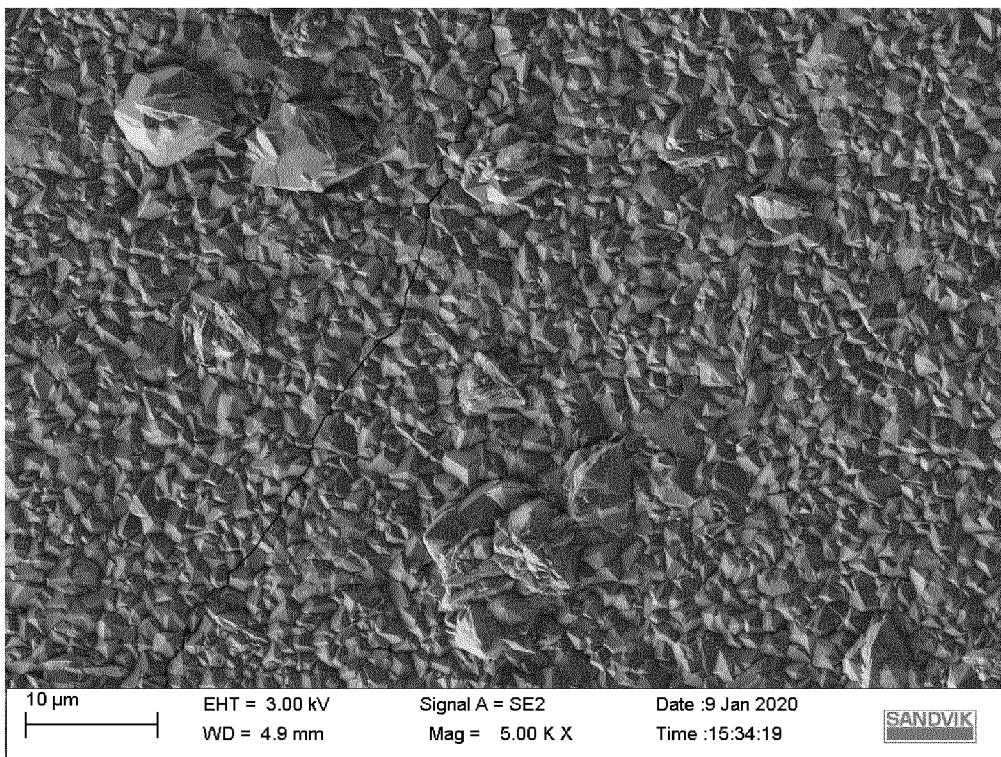


Fig. 8

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2021/082473

A. CLASSIFICATION OF SUBJECT MATTER INV. C23C28/04 C23C30/00 ADD.		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) C23C C22C		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal, WPI Data		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	TOLLER LISA ET AL: "Investigation of cemented carbides with alternative binders after CVD coating", INTERNATIONAL JOURNAL OF REFRACTORY METALS AND HARD MATERIALS, ELSEVIER, AMSTERDAM, NL, vol. 62, 5 July 2016 (2016-07-05), pages 225-229, XP029829432, ISSN: 0263-4368, DOI: 10.1016/J.IJRMHM.2016.07.005 pages 225-228; tables 1, 2 -----	1-15
A	JP 2003 342667 A (KYOCERA CORP) 3 December 2003 (2003-12-03) the whole document ----- -/--	1-15
☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents : "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance;; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search		Date of mailing of the international search report
16 December 2021		04/01/2022
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer Martinavicius, A

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2021/082473

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	US 2012/231227 A1 (KANAOKA HIDEAKI [JP] ET AL) 13 September 2012 (2012-09-13) the whole document -----	1-15

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