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A COMPARISON BETWEEN CVD AND PVD COATED CEMENTED CARBIDE CUTTING TOOLS

R. PORAT and Y. CASSUTO

Iscar Ltd., PO. Box 34, IL-Nahariya 22100, Israel

Resume - Les outils de coupe devant supporter des contraintes au cours de leur emploi en usinage, nous étudions des outils qui non seulement résistent à l'usure mais conservent aussi leurs propriétés mécaniques -- aptitude à supporter la coupe interrompue, le choc thermique, et des charges cycliques, aussi bien que la résistance à l'usure. Dans le présent travail, nous comparons les résultats d'essais de rainurage et de fraisage effectués avec des métaux durs de type ISO K25 et ISO K35 revêtus par les procédés de revêtement C.V.D. et P.V.D. Les revêtements C.V.D. sont TiCN ou une combinaison de TiN et TiC. À titre de comparaison, les mêmes substrats ont été revêtus de TiN ou (Ti,Nb)N par deux procédés P.V.D.

Abstract - Because cutting tools must withstand the stress conditions of machining, we are investigating cutting tools which not only will be wear resistant, but which will also retain their mechanical properties -- the ability to withstand interrupted cuts, thermal shock and a cycling load as well as wear resistance. In this work we compare the results of grooving and milling tests made on hardmetals ISO K25 and ISO K35 coated by C.V.D. and P.V.D. coating processes. The CVD coatings were of TiCN or a combination of TiN and TiC. For comparison the same substrates were coated by two PVD processes with TiN or (TiNb)N.

1 - Introduction

Following the success of P.V.D. coated H.S.S. tools, work has been carried out on the possibilities of using P.V.D. coatings for cemented carbide cutting tools. In operations such as milling, drilling, broaching, tapping and threading the P.V.D. coating of H.S.S. tools has allowed an increase of the machining speed up to 70 m/min., or when using the normal speeds of 30-50 m/min. the P.V.D. coating has more than doubled tool life.

Since H.S.S. tools can not be coated using a high temperature process, the issue of using a C.V.D. coating process does not arise. However, for cemented carbides cutting tools the C.V.D. coating process is well established so a few questions arise before the new P.V.D. method is used:

1. Is it possible to obtain a good adhesion between the coating and the substrate? If yes, what coating conditions (including preparations) would ensure the good adhesion.
2. How does the P.V.D. coating change the mechanical properties of the substrate? Is there a decrease in strength or any other change in the cutting edge?

In the C.V.D. coating process it is possible to obtain a good adhesion between coating and substrate, but the mechanical properties of the cutting edge may change through the formation of the brittle η phase. Nevertheless, the C.V.D. coating process has proved itself as valuable addition to the cemented carbide industry and any new coating such as the P.V.D. coating would have to prove itself compared to the C.V.D. coating.

2 - Experimental Procedure

2.1 -The Grades Used

In order to check if a P.V.D. coating would be able to compete with a C.V.D. coating we choose two cutting applications in which a tough coated cutting tool is needed: cut-off or grooving and milling.

In the cut-off and grooving application the cutting speed changes continuously from a maximum to a minimum and the narrow space for chip removal causes the chips to strike the cutting edge. The milling application is particularly difficult because of interrupted cuts which cause a cycle of maximum stress and temperature followed by no stress and room temperature.

The object of the experiment was to find the effect of the different coating processes on the mechanical properties, tool life and machining speeds.

The cut-off and grooving geometries used were GFN-3B of an ISO K35 grade and GTN-3 of a ISO K25 grade. The milling geometry used was SPK 42 EDTR or EDL of the same grades as above. Apart from the machining tests a transverse rupture strength (TRS) test was also carried out on the ISO K25 and ISO K35 grades and also on ISO P25 and P40 grades. Table 1 shows the composition and table 2 shows the mechanical properties of the different grades.

Table 1. Composition of the Grades Used in Weight Percent.

Grade	WC	Co	TiC	TaC	NbC	Grain size (μ)
K25	90	8	-	1.8	0.2	2
K35	90	8	-	1.8	0.2	6
P25	68	11	7	12.6	1.4	2
P40	77	11	4	7.2	0.8	2

Table 2. The Mechanical Properties of the Grades Used.

Grade	Hardness (RA)	Young's modulus (kN/mm ²)	TRS (N/mm ²)
K25	91.5	580	2350
K35	89.7	580	2690
P25	91.7	540	2520
P40	90.7	560	2350

2.2 - The C.V.D. Coating

Three types of C.V.D. coatings were used in our experiments. The first and second coatings (type "A" and "B" respectively) are triple layer coatings, and the third coating (type "C") is a single layer coating. The coatings are of the following compositions:

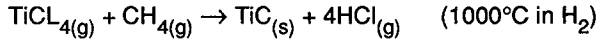
Type "A": TiC (5 μ thick) + TiCN (1 μ thick) + TiN (2 μ thick).

Type "B": TiN (1 μ thick) + TiC(2.5 μ thick) + TiN (1.5 μ thick).

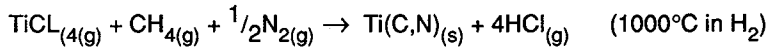
Type "C": TiCN (7 μ thick).

Prior to the coating deposition the substrates had been cleaned by sand blasting and ultrasonic cleaning in freon. Surface oxides on the substrates were reduced during heating (to a temperature of 1000°C) in a hydrogen atmosphere. The different layers were nucleated according to the following reactions:

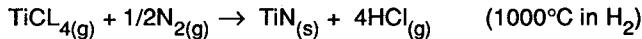
TiC layer:



TiCN layer:



TiN layer:



2.3 - The P.V.D. Coating

Two P.V.D. coating methods were used in our experiments. The first, thermoionic arc evaporation, was used to deposit a TiN layer. The second method, cathode spot arc evaporation was used to deposit TiN and also (TiNb)N single layers.

The thermoionic arc evaporation process (will be referred to as method number 1) is based on the evaporation of Ti using an electron beam, the formation of Ti and N ions plasma and the electric attraction of those ions to the part being coated. The arc is formed between a resistance heated filament (the anode) and the Ti source (the cathode) in a relatively high pressure (about 1 Torr) of Ar gas. N₂ gas is added into the system and is ionized by the arc. The N and Ti ions then react on the substrate to form a TiN coating.

The cathode spot arc evaporation process (will be referred to as method number 2) is based on an electric arc in vacuum between two electrodes which forms on the cathode a localized work spot (the cathode spot). The current density on the cathode spot can reach very high values causing the localized heating of the cathode material and its evaporation. The evaporated gas undergoes ionization by the arc, the metal and nitrogen ions are attracted to the substrate and react to form a coating. Since very high temperatures can be reached on the cathode spot, it is also possible to use metals with an evaporation temperature higher than the Ti evaporation temperature.

3 - Results

3.1 - TRS results

The transverse rupture test (TRS) results are in Table 3.

Table 3. The Transverse Rupture Test Results.

Grade	Uncoated	CVD type"B"		Method 2 (TiN)		Method 1 (TiN)	
	TRS(N/mm ²)	Thickness(μ)	TRS(N/mm ²)	Thickness(μ)	TRS(N/mm ²)	Thickness(μ)	TRS(N/mm ²)
K25	2350	5	1800	3	2290	5	2240
K35	2690	5	2140	3	2680	5	2350
P25	2520	5	1550	3	2010	5	1940
P40	2350	5	1810	3	2120	5	1990

3.2 - The Grooving Results

The ISO K25 GTN-3 inserts were tested on a AISI 4140 alloyed steel under the following conditions:

Speed : 200 m/min.
 Feed : 0.2 mm/rev.
 Depth of groove : 15 mm.

The wear (VBH) was measured after the first groove was cut, after the sixth groove and after the tenth groove. Figure 1 shows the results of C.V.D. (type "A") coated and TiN P.V.D. (method number 1 and method number 2) coated inserts. Figure 2 compares TiN and (TiNb)N P.V.D. coated inserts (method number 2).

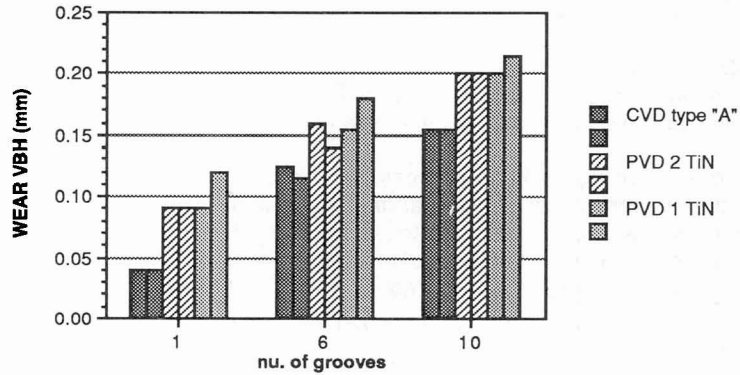


Figure 1. Wear as a function of grooving cuts for C.V.D. and P.V.D. TiN coated ISO K25 GTN-3 inserts at 200 m/min.

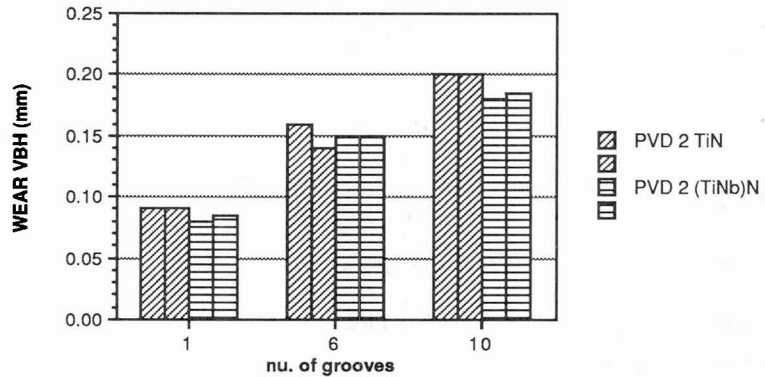


Figure 2. Wear as a function of grooving cuts for P.V.D. TiN and (TiNb) coated ISO K25 GTN-3 inserts at 200 m/min.

The ISO K35 GTN-3B inserts were tested on a AISI 326 stainless steel under the following conditions:

Speed : 100 m/min.
 Feed : 0.2 mm/rev.
 Depth of groove : 15 mm.

The wear (VBH) was measured after the first groove was cut, after the sixth groove and after the tenth groove. Figure 3 shows the results of C.V.D. (type "B") coated and TiN P.V.D. (method number 1 and method number 2) coated inserts. Figure 4 compares TiN and (TiNb)N P.V.D. coated inserts (method number 2).

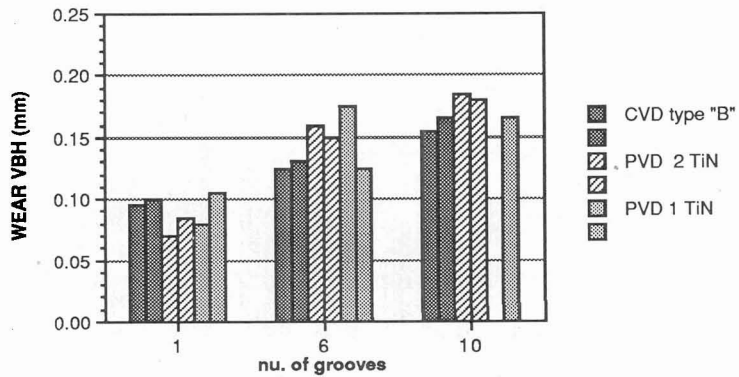


Figure 3. Wear as a function of grooving cuts for C.V.D. and P.V.D. TiN coated ISO K35 GFN-3B inserts at 100 m/min.

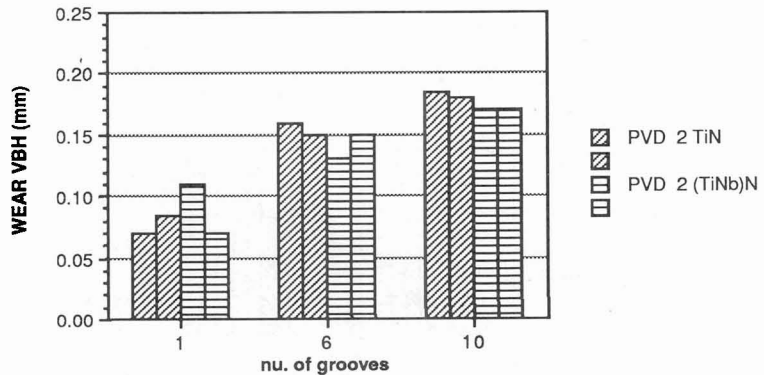


Figure 4. Wear as a function of grooving cuts for P.V.D. TiN and (TiNb)N coated ISO K35 GFN-3B inserts at 100 m/min.

3.3 - The Milling Results

The ISO K25 and ISO K35 milling inserts were tested on a AISI 1060 carbon steel under the following conditions:

Speed : 241 m/min, the ISO K35 also at 145 m/min.
 Depth of cut : 0.2 mm/rev.
 Diameter of milling cutter : 100 mm (single tooth).
 Workpiece dimensions : width 60 mm, length 700 mm per pass.

The feed was increased every pass according to the following chart:

Pass number	1	2	3	4	5	6
Feed (mm/tooth):	0.10	0.13	0.17	0.21	0.26	0.34

The wear was measured after each pass was completed.

Figure 5 shows the results of C.V.D. (type "C") coated and TiN P.V.D. (method number 1 and method number 2) ISO K25 coated inserts. Figure 6 compares TiN and (TiNb)N P.V.D. ISO K25 coated inserts (method number 2).

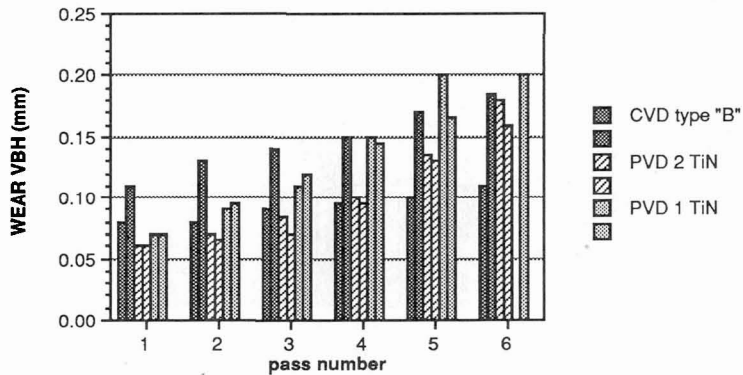


Figure 5. Wear as a function of milling passes for C.V.D. and P.V.D. coated ISO K25 milling inserts at 241 m/min.

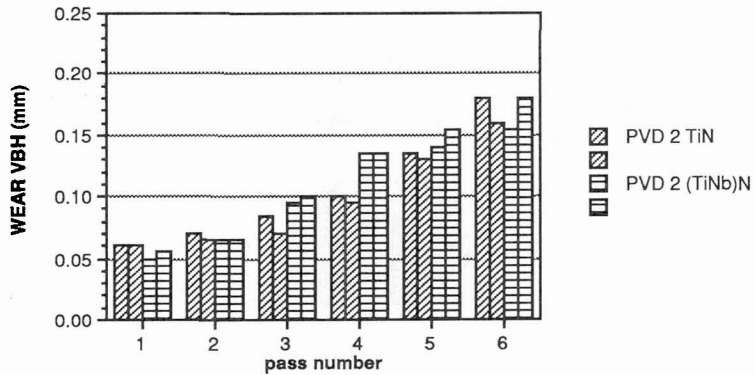


Figure 6. Wear as a function of milling passes for P.V.D. TiN and (TiNb)N coated ISO K25 milling inserts at 241 m/min.

Figure 7 shows the results of C.V.D. (type "B") coated and TiN P.V.D. (method number 1 and method number 2) ISO K35 coated inserts at 241 m/min. Figure 8 compares TiN and (TiNb)N P.V.D. ISO K35 coated inserts (method number 2) at 241 m/min. Figure 9 shows the results of C.V.D. (type "B") coated and TiN P.V.D. (method number 1 and method number 2) ISO K35 coated insert at 145 m/min.

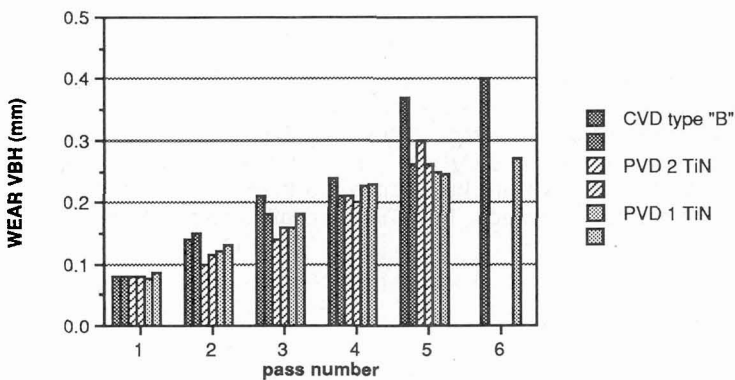


Figure 7. Wear as a function of milling passes for C.V.D. and P.V.D. coated ISO K35 milling inserts at 241 m/min.

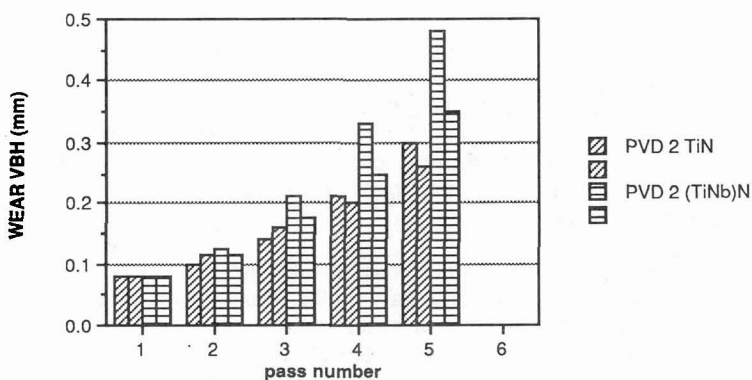


Figure 8. Wear as a function of milling passes for P.V.D. TiN and (TiNb)N coated ISO K35 milling inserts at 241 m/min.

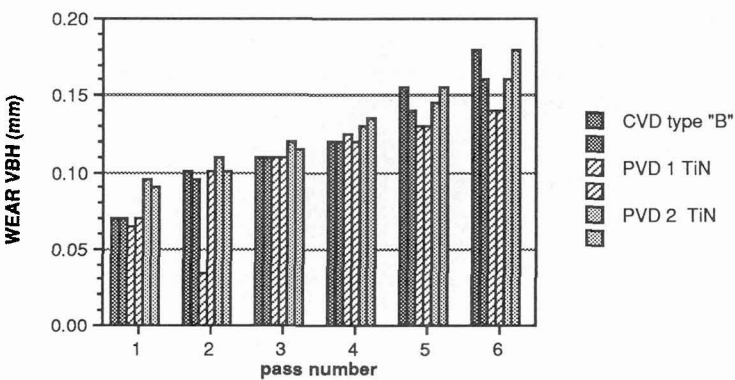


Figure 9. Wear as a function of milling passes for C.V.D. and P.V.D. coated ISO K35 milling inserts at 145 m/min.

4 - Discussion

4.1 - Grooving

In grooving, at high speeds (such as were used for testing the GTN-3 ISO K25 inserts) the C.V.D. coating had an advantage over the P.V.D. coatings. At lower machining speeds (such as were used for testing the GTN-3B ISO K35 inserts) the C.V.D. and P.V.D. coatings performed equally well. The cathode spot arc evaporation (method number 2) P.V.D. coatings were better than the thermoionic arc (method number 1) coating at both machining speeds. The (TiNb)N coating had a slight advantage over the TiN coating.

4.2 - Milling

In milling all coatings gave comparable results. The ability of a P.V.D. coating to compete successfully with a C.V.D. coating at normal milling machining speeds has been shown previously, but the results we have received show that P.V.D. coatings are also successful at high milling machining speeds, up to 241 m/min.

5 - Summary

The C.V.D. coating caused a decrease in strength of between 20 to 40 percent. The two P.V.D. coating processes gave a similar decrease in strength considering the fact that the coating from method number 2 was thinner than the coating from method number 1. The P.V.D. method number 1 coating (which was of the same thickness as the C.V.D. coating) caused a decrease in strength of only 5 to 20 percent, much less than the C.V.D. coating. This shows then in respect to strength the P.V.D. coatings have an advantage over C.V.D. coatings.

The edge toughness was measured in milling with feeds up to 0.34 mm/tooth. None of the coated inserts with a ISO K25 substrate broke, while some of the coated inserts with a ISO K35 substrate broke regardless of the coating type. The failures of the coated inserts with a ISO K35 substrate was caused either from a large wear or plastic deformation of the substrate.

At low machining speeds, 100 m/min in grooving and 145 m/min in milling, there was no significant difference between the different coatings. At higher machining speeds there is probably a top value for using P.V.D. coatings and only C.V.D. coatings can be used for higher speeds. This top value seems to be about 250 m/min. There is no conclusive prove that P.V.D. coatings have an advantage over a C.V.D. coatings.

When comparing the two P.V.D. methods, method number 2, cathode spot arc evaporation, has an advantage over method number 1, thermoionic arc evaporation. At low speeds the (TiNb)N coating has an advantage over the TiN coating.