

# Cutting performance of cemented carbide tools with nano-crystalline pvd coatings

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*Abstract:* This resource deals with the analysis of properties of hard coatings and wear resistance of chemical vapour deposition (PVD) coated technology. It focuses on the preparation, execution and evaluation of test coatings on the front ball-milling cutters. Examination of these characteristic properties may give into an insight to the reason why some systems show excellent wear characteristic.

*Key-Words:* PVD, properties of coatings, testing, analysis, frontal spherical milling cutter, durability

## Introduction

The coating of cutting tools by hard material layers with the aim to rise their durability has reached a high level. Modern coating methods are have become an important part of industry. Wear resistance, durability, toughness (breakage resistance) and hot hardness (high hardness and chemical stability at high temperature) are the four main properties necessary for high speed use of cemented carbide. These proprieties are for productivity, economy and ecology.

The high-purity, solid coating material (metals such as titanium, chromium and aluminium) is either evaporated by heat or by bombardment with ions (sputtering). At the same time, a reactive gas (e.g. nitrogen or a gas containing carbon) is introduced; it forms a compound with the metal vapour and is deposited on the tools or components as a thin, highly adherent coating. In order to obtain a uniform coating thickness, the parts are rotated at uniform speed about several axes. The properties of the coating (such as hardness, structure, chemical and temperature resistance, adhesion) can be accurately controlled. The physical vapour deposition processes include arc evaporation, sputtering, ion plating, and enhanced sputtering [1].

Physically vapour deposited coatings offer a powerful alternative to improve further the cutting performance of the cutting materials. The flexibility of coating processes of the physical vapour deposition (PVD) method, well supported by the superior and controllable properties of coatings are responsible for the almost exclusive worldwide application of coated tools. [2]

Physical vapour deposition may have a considerable influence on performance in practical use and thus on protective qualities. Coatings allow excellent cutting performance allowing a beneficial of modern CNC machine tools. PVD coatings protect cutting tools against abrasion, adhesion, diffusion, formation of comb cracks and other wear phenomena. The choice of the proper substrate or the correct protective coating in the specific machining operation is very important.

## Material and Methods

The goal of testing was to compare cutting performance of cemented carbide frontal spherical milling cutter FW412.16.100.10 with four cutting edge, diameter Ø16, length 100 mm and full cemented carbide (two fabrications):

Wear resistance: cutting force 300 N and observable effects of wear (sparking of tool, cutting edge stability and vibration).

1. Cemented carbide milling cutter (reference)
2. Cemented carbide milling cutter with:
  - Nc-gradient coating (tumbling by granulate with grinding paste)
  - nc- monolayer coating (tumbling by granulate with grinding paste)
  - Nc-multilayer (tumbling by granulate with grinding paste)
  - Nc-monolayer coating (no tumbling)

Fig. 1 Cemented carbide front ball-milling cutter



Fig. 2 Micrograph of a surface of the coating deposited tool at 8x

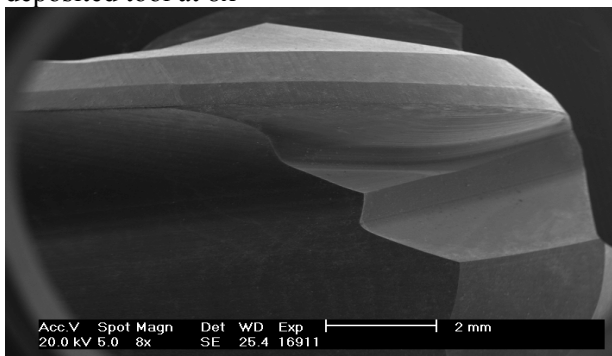


Fig. 3 Micrograph of a surface of the coating deposited tool at 50x

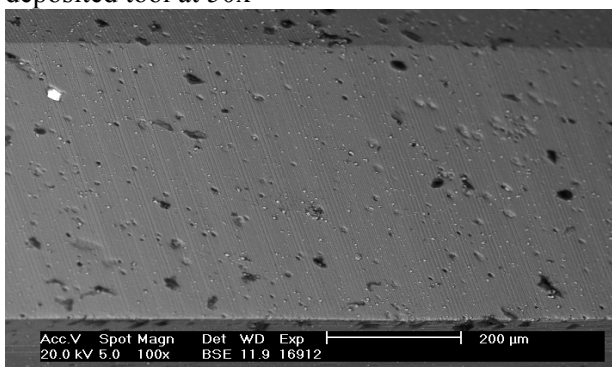


Fig. 4 Micrograph of a surface of the coating deposited tool at 100x

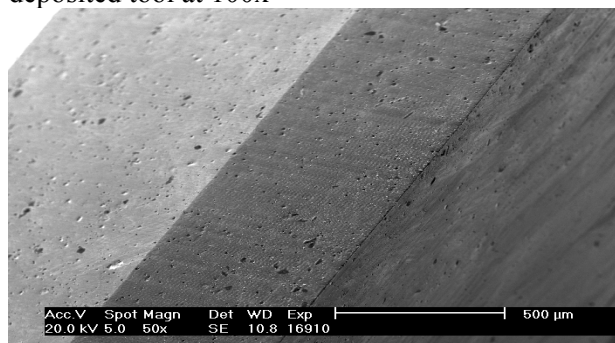
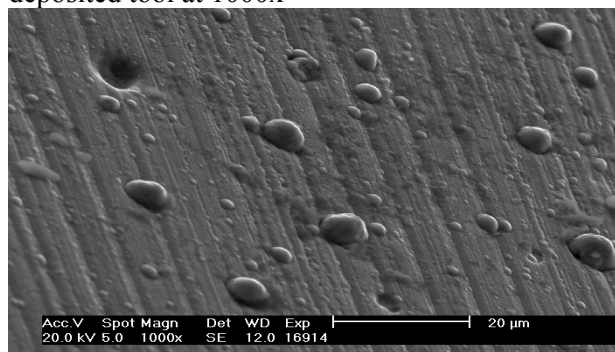


Fig. 5 Micrograph of a surface of the coating deposited tool at 1000x



### Workpiece material

The cutting performances are evaluated by machining cast steel GGG70 (ductile iron with spheroid nodular graphite), semi-finished product 90 x 80 – 300 mm. The surface was not clear of casting, inclusion and other surface defects.

### Fastening of cutting tools

The cemented carbide frontal spherical milling cutters were fastened with minimal extends in hydraulic tool holder RÖHM 40x16, DIN 69871Fr. This hydraulic tool holder was hydraulically fastened to the spindle head. Tight fastening was main tainted throughout the experiment.

### Cutting conditions

Table 1 Cutting conditions during experimental

Cutting conditions	Period	Value
Cutting speed - vc	[m/min]	250 m/min
Rotational speed - n	[rpm]	4980
Feed speed - vf	[mm/min]	400
Feed per tooth - fz	[mm]	0,02
Cutting depth - ap	[mm]	8
Cutting width - ae	[mm]	0,5
Cooling, lubricating	-	-
Type of milling		conventional milling/ climb milling
Wear criteria		Wear effect(spark of tool, cutting edge stability, ineffective cut, colour of cut and vibration)

### Milling machine

A console milling machine type FV 25 CNC with control system Heidenhain 315 TNC manufactured by O.S.O. ltd. Olomouc was used.

### Reading method of loading tool, methods of measurement and analysis of measure data

In general, tool life is dependent on temperature, pressure compatibility between tool and work materials, and the structural inhomogeneity of the tool material. Axial force, radial force and tangential force were measured using a piezoelectric silicon dynamometer KISTLER 9257B supplied by charge amplifier KISTLER 9011A controlled by PC. Sampling rate was 50 Hz.

This method provided basic source signals of force loading in coordinate system of milling machine. Measurement was focused to axes X, Y, Axis Z

Force (axis of spindle) was about 5 – 10% of those on the significant axes X and Y. The advantage of measurement of cutting forces during milling was that it allowed of progress of wear as a consequence force change. This allowed observation of the gradual

wear of the tool without the need for measurement, disassembly, cooling and reassembly.

### Comparison of results

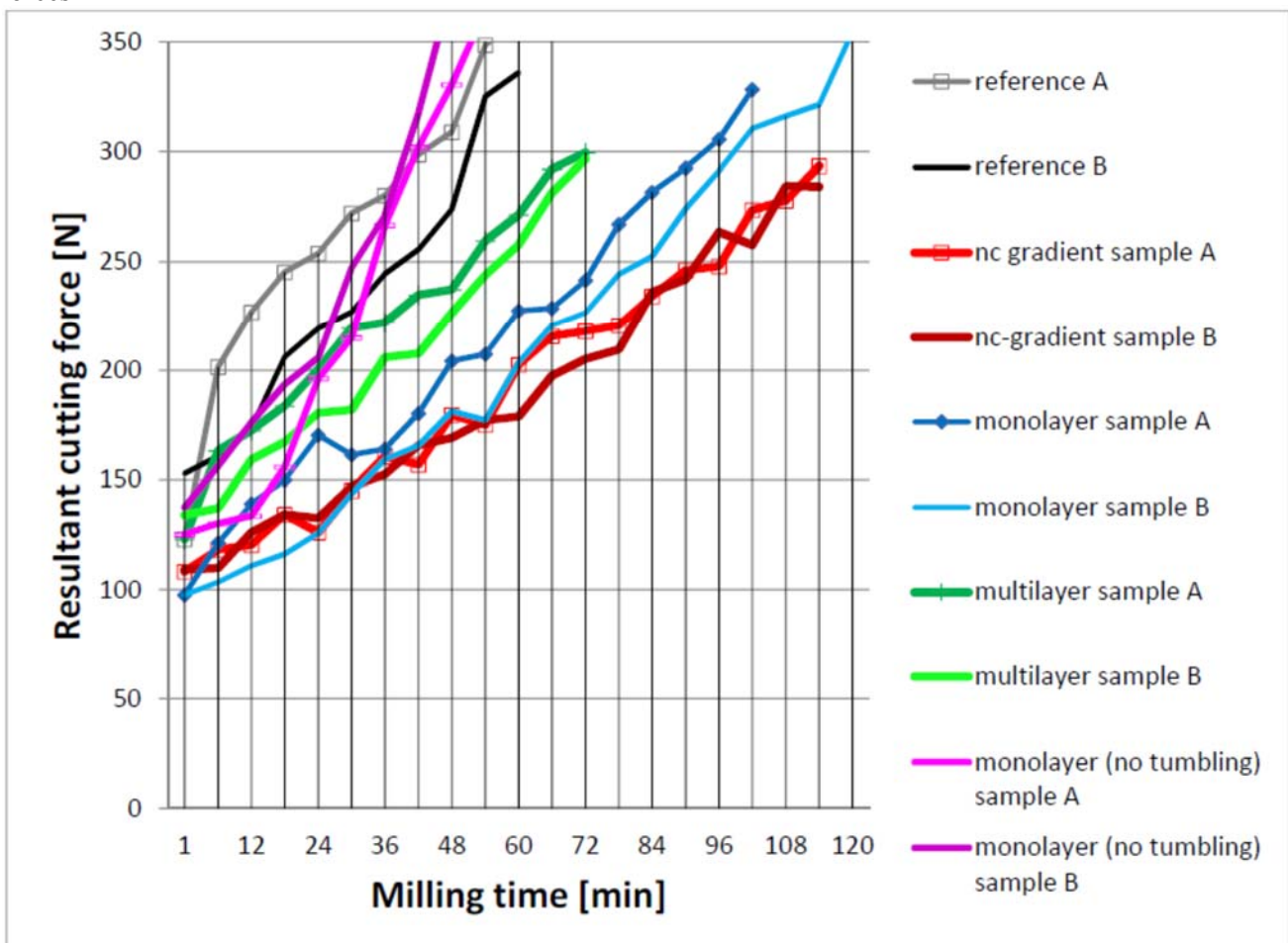
Achieved results and integrated results for individual milling tools are shown in table 2.

See graph 1, which shows progression of average value of resultant cutting forces achieved during milling.

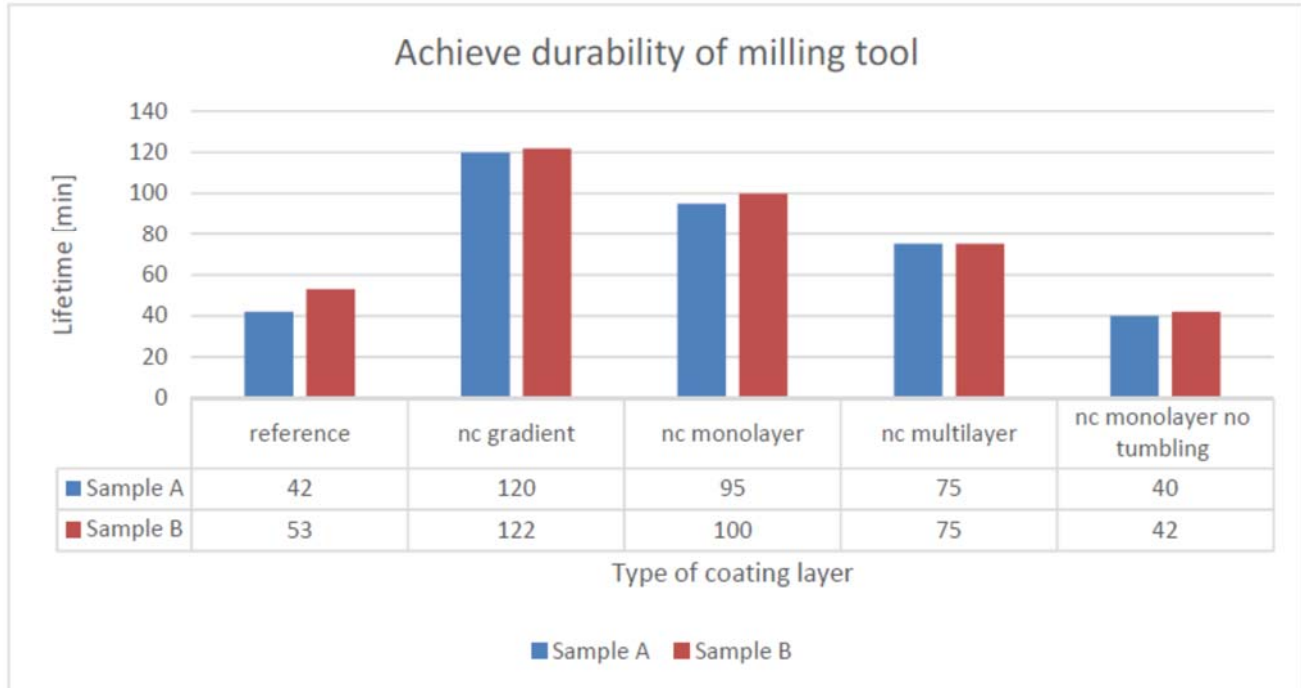
Table 2 Achieved average value of resultant cutting forces

Time [min]	Refer. A	Refer. B	1A	1B	2A	2B	3A	3B	4A	4B
1	123.1	152.9	108.2	109.1	97.5	97.5	123.1	134	125.2	137.6
6	201.6	160.8	118.2	109.8	121.4	103.4	163.3	137.1	130.2	156.3
12	226.9	173.5	120.5	126.2	139.1	110.8	172.5	159.3	133.8	176.3
18	245.3	206.2	134.4	134.4	149.9	116.2	183.8	167.3	155.9	193.6
24	253.8	219.3	126.1	132.7	170.4	125.9	200.6	180.6	196.3	205.9
30	272.3	227	145.2	147.1	161.4	143.7	219.5	181.9	215.1	247.4
36	280.2	244.4	160.7	152.5	164.1	159.2	222.2	206.1	266.6	271
42	298.7	255.5	156.9	165.7	180.2	165.7	234.8	207.8	302.1	317.4
48	308.9	274	179.6	169.2	204.4	181.4	237.3	226.5	330.5	375.1
54	348.6	325.1	175.1	177.2	207.5	177.4	259.5	243.9	364.6	
60	360.2	336	202.7	178.9	227.5	203.7	271.4	257.7		
66	371.6		215.8	197.5	228.7	220.7	292.2	281.4		
72			218.1	205.3	241.5	226.6	299.6	296.6		
78			220.8	209.6	267.1	244.3				
84			234.2	236	281.7	252.4				
90			246.1	242	292.7	274.3				
96			247.9	263.6	305.6	291.4				
102			273.6	257.7	328.4	310.4				
108			277.9	284.4		316.1				
114			293.5	284.2		321.4				
120						354.7				

Graph 1 Progression average value of resultant cutting forces



Graph 2 Achieved durability of milling tool



### Results and Discussion

Experiments of cutting power were made by selection of coatings on cemented carbide frontal spherical milling cutters FW412.16.100.10, made of cast steel GGG70 (ČSN 422307).

Procedure which was used precisely describes wear resistance of milling tools during machining process.

The samples of milling cutters showed very little variation between tools, which indicates very good manufacture (sharpening) of tools, PVD coating, methods of calibration and measure of forces.

Conditions during experiments were less sophisticated than could be expected in manufacturing conditions. In practise other benefit and cost reduction can be expected.

As additional control criterion was observation of sparking of milling cutter in climb milling – if achieved there was occurrence of improvement cutting forces.

In terms of side effects, sparking of graphite reference tool was detected after five feeds of tooth in conventional milling cutters, while in the other tools the sparking of graphite was detected much later (**50 feeds of tooth**).

### Conclusion

The best result is for a milling cutter with a gradient coating – machining process was very stable with good results of forces. Forces had linear progress without high amplitude during milling all the time.

The best coating can be achieved by both monolayer coating and multilayer coating. The worst coatings were reference tool and monolayer coating without tumbling (granulate with grinding paste).

The durability of the mill cutting tool coated by the gradient method exceeded useful milling-cutter's durability by 200% (120 minutes) compared with the reference milling-cutter (53 minutes)

### Acknowledgement

The research has been supported by the project TP 4/2014: Analysis of degradation processes of modern materials used in agricultural technology; financed by IGA AF MENDELU.

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