ACTA UNIVERSITATIS AGRICULTURAE ET SILVICULTURAE MENDELIANAE BRUNENSIS

Volume 63 161 Number 5, 2015
http://dx.doi.org/10.11118/actaun201563051477

ANALYSIS OF PROPERTIES OF HARD COATINGS AND WEAR RESISTANCE OF CHEMICAL VAPOUR DEPOSITION (PVD) COATED TECHNOLOGY

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Abstract

HUDEČEK PAVEL, DOSTÁL PETR. 2015. Analysis of Properties of Hard Coatings and Wear Resistance of Chemical Vapour Deposition (PVD) Coated Technology. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis,* 63(5): 1477–1483.

Modern coating methods are having 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 technological properties necessary for durability and long life time. These proprieties are for productivity, economy and ecology very important point.
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.

Keywords: PVD, properties of coatings, analysis, milling cutter, durability, wear resistance

INTRODUCTION

The coating of cutting tools and machines parts such as gearboxes, hydraulics, pumps, transmissions by hard material layers with the aim to rise their durability has reached a high level. Agricultural and forestry machines parts could have higher wear and corrosion resistance, pick-up, galling and fretting shall be reduce, friction and release forces are decrease during operation. PVD coating surfaces have much more productivity, profitability and reliability of the process and equipment. Likewise most of rotating parts use mechanical face seals to prevent leaks, exclude abrasive media and lubricate the mechanical assemblies. Seal reliability is critical for overall equipment reliability as seal failure can damage expensive equipment while inflicting high downtime costs.

In many industrial processes such as in conveying, mixing and separating in the agricultural and forestry machines, machining process, steel and iron industry, cement industry, coal power plants, overground and underground working, recycling and environmental protection, the wear of instruments and other work equipment plays a significant role and also contributes to the costs. The choice of materials, which can increase wear resistance of work instruments, is highly important. One successful method for increasing instrument lifespan is surface coating. The process of surface coating helps to control friction and wear, improve corrosion resistance and reduce costs (Bach and Mellor, 2004, 2006).

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 (Oerlikon). Improvement of the coating systems (monolayer coating, multi-layer, multi-component, gradient coating) systems will enable more widespread use in the future. However, due to the very complex manufacturing process involved, for most applications it is too expensive.

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 (Bouzakis *et al*., 2001).

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).

Cemented carbide milling cutter (reference)

Cemented carbide milling cutter with:

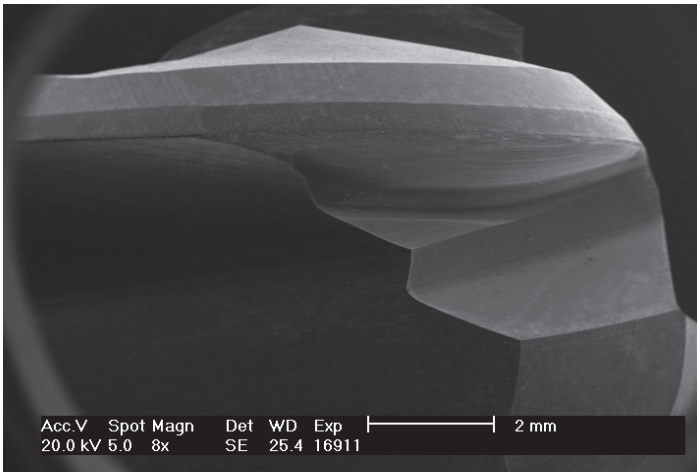
Nc-gradient coating (tumbling by granulate with grinding paste),

Nc-monolayer coating (tumbling by granulate with grinding paste),

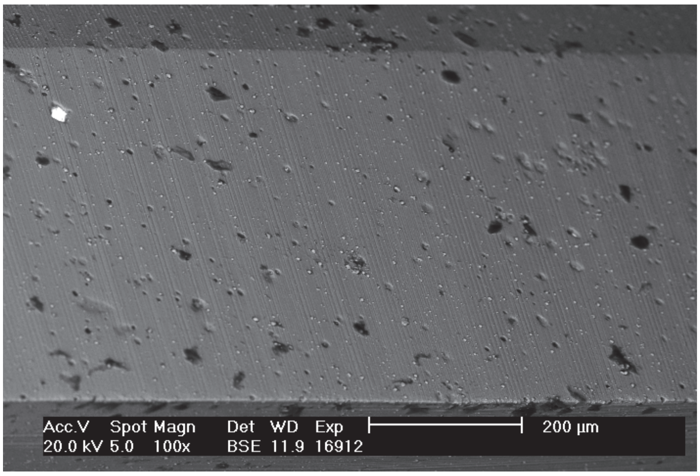
Nc-multilayer (tumbling by granulate with grinding paste),

Nc-monolayer coating (no tumbling).

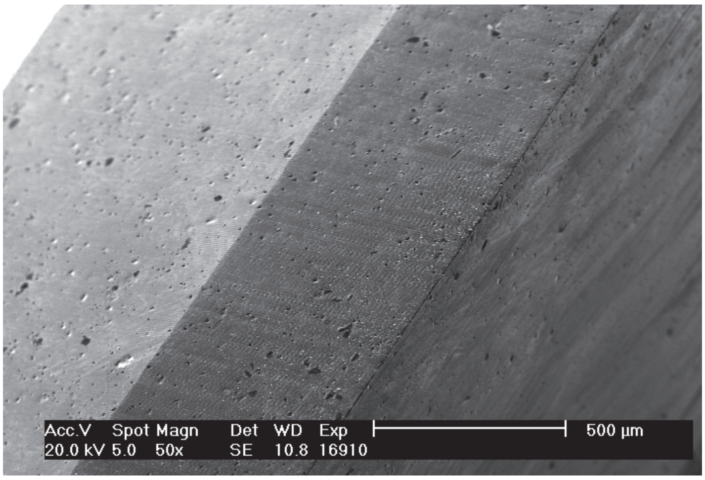
1: *Cemented carbide front ball-milling cutter*



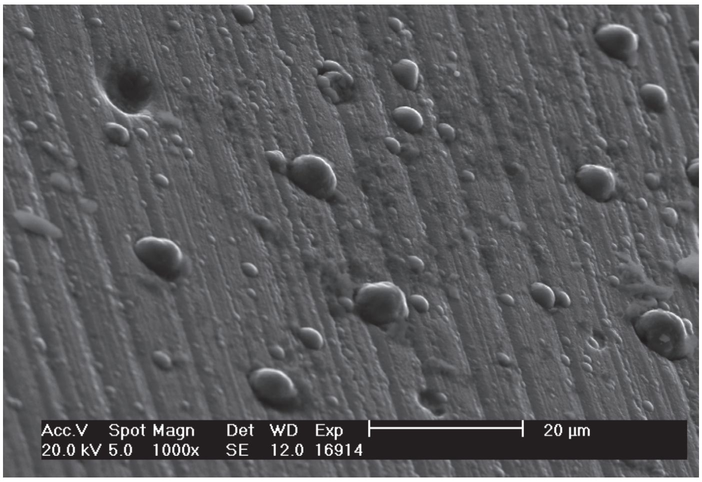
2: *Micrograph of a surface of the coating deposited tool at 8×*



3: *Micrograph of a surface of the coating deposited tool at 50×*



4: *Micrograph of a surface of the coating deposited tool at 100×*



5: *Micrograph of a surface of the coating deposited tool at 1000×*

Workpiece Material

The cutting performances are evaluated by machining cast steel GGG70 (ductile iron with spheroid nodular graphite), semi-finished product 90×80–300 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.

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.

Cutting Conditions

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 are 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 shows in Tab. II.

See Fig. 6, which shows progression of average value of resultant cutting forces achieved during milling.

RESULTS AND DISCUSSION

Today there are thousands of applications of vacuum coating technologies. It is hard to realize that the industry is only about 70 years old. The vapour sources for vacuum coating are 100 to 150 years old but commercial uses did not start until the mid- 1930s with the development of thermal evaporation in vacuum. The applications of vacuum coatings progressed from the simple single-layer coatings used for electrical, optical, and reflecting applications in the 1930s and 1940s to coatings for corrosion protection in the 1950s. In the 1990s hard coatings for tools and decorative applications became important new applications. In the future it is expected that vacuum coatings will continue to play a vital role in developing both existing and new products. An example is the optically variable interference / diffraction films that are fractured and used as pigments in ink to counter counterfeiting (Mattox, 2003).

By the coating could be coated many mechanical parts for high wear resistance such as bearing, ploughing machine or cutting tools for high temperature resistance respectively enormous durability. Coatings protect mechanical parts, tools etc. against abrasion, adhesion, diffusion, formation of comb cracks and other wear phenomena.

This 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.

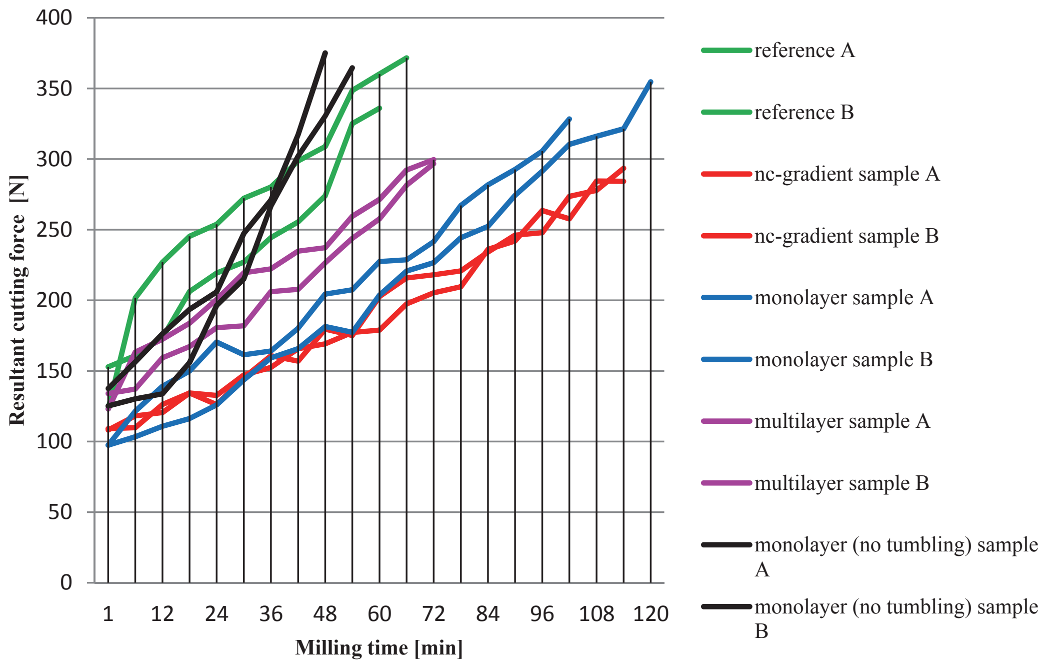
The samples of milling cutters showed very little variation between tools, which indicates very good manufacture (sharpening) of tools, PVD coating, methods of calibration and measure of forces.

I: *Cutting conditions during experimental*

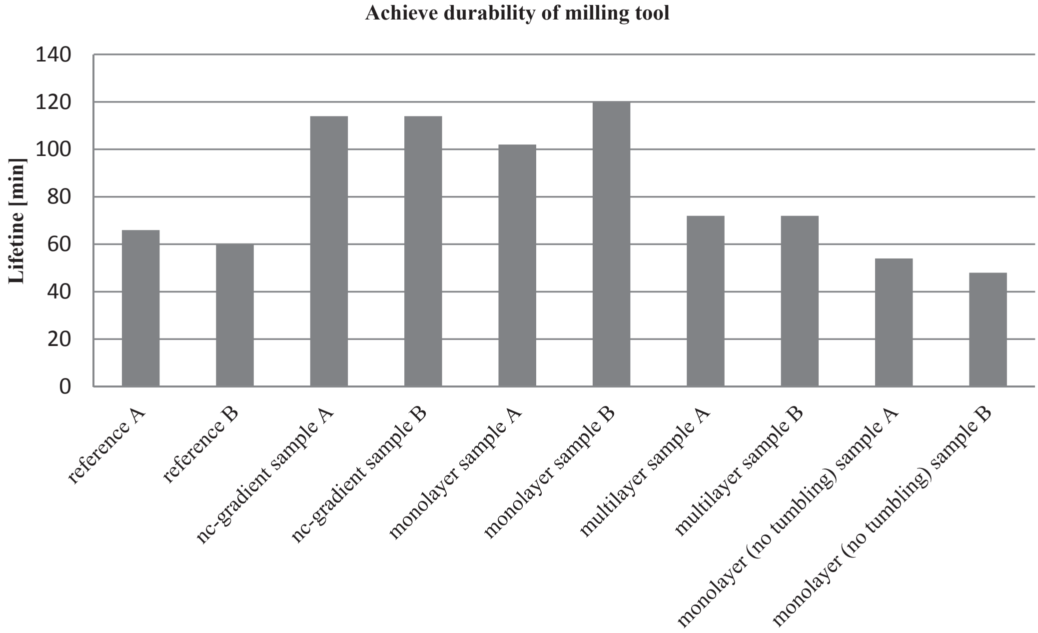
Cutting conditions	Period	Value
Cutting speed [vc]	[mxmin^{-1}]	250
Rotationl speed [n]	[rpm]	4980
Feed speed [vf]	[mmxmin^{-1}]	400
Feed per tooth [fz]	[mm]	0,02
Cutting depth [ap]	[mm]	8
Cutting width [ae]	[mm]	0,5
Cooling, lubricating	-	-
Type of milling		Conventional milling/climb milling
Wear criteria		Wear effect (spark of tool, cutting edge stability, ineffective cut, colour of cut and vibration)

II: *Achieved average value of resultant cutting forces*

Time [min]	reference A	reference B	nc-gradient sample A	nc-gradient sample B	monolayer sample A	monolayer sample B	multilayer sample A	multilayer sample B	monolayer (no tumbling) sample A	monolayer (no tumbling) sample B
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				



6: *Progression average value of resultant cutting forces*



7: *Achieved durability of milling tool*

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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