EVALUATION OF PROPERTIES OF MULTILAYER AND MULTICOMPONENT PVD COATINGS DEPOSITED ON THE CUTTING TOOLS PRODUCED BY POWDER METALLURGY

D. Jakubéczyová [1], M. Hagarová [2], J. Savková[3]
[1]Institute of Materials Research, Slovak Academy of Sciences, Košice, Slovakia,
[2]Department of Materials Science, Faculty of Metallurgy, Technical University of Košice, Slovakia
[3]New Technologies – Research Centre, University of West Bohemia, Universitní 8, 306 14 Plzeň, Czech Republic

Received 30.01.2012
Accepted 31.03.2012

Corresponding author: *Mária Hagarová, Telephone number: +421 55 602 2541, Department of Materials Science, Faculty of Metallurgy, Technical University of Košice, Letná 9, 040 01 Košice, Slovakia, E-mail: maria.hagarova@tuke.sk*

Abstract
The paper deals with the evaluation of properties of the thin PVD layers applied on the tools made by powder metallurgy. This PVD technology belongs to the modern methods of depositing thin layers onto the surface of machine (tools and tool parts). Technological methods of the deposition process of thin layers are constantly improved. At present new types of layers are developed. The evaluation of structure, composition and properties of layers were controlled during whole coating process. TiAlN layer and nanocomposite layer used increase the life-time of cutting tools. So, there is important to analyse the coated material behaviour under the contact conditions. Thin AlTiN multilayer was deposited by ARC technology and nanocomposite layer nc-AlTiN/Si_3N_4 by LARC technology. The properties of the system thin layer - steel substrate were tested by roughness, hardness measuring and by pin-on-disc test at room and elevated temperatures. These properties were tested using Atomic force microscope (AFM), Vickers indenter, Calotest and Pin-on-disc tribometer. The HV0.5 hardness values were 21.5 ± 2.5 GPa for AlTiN multilayer and 23.9 ± 0.7 GPa for nACo layer. Values of coefficient of friction for nACo layer were lower those for AlTiN layer. Analysis of the employed coating systems indicates their possible applications on selected type of powder metallurgy steel tools and a possibility for an increase of the lifetime under working conditions.

Keywords: PVD, layer, properties, AFM, Pin-on-disc

1 Introduction

At present the PVD layers – mostly on the machining – competitive in ambitious word trade. The reasons are: a high surface hardness of layers is one of the best ways to increase tool life – time, wear resistance is the ability of the layer to protect against abrasive and adhesive wearing, a higher oxidation resistance of PVD layers provides performance in high temperature service and they keep surface hardness at elevated temperature [1-5]. The thin layers have very good corrosion resistance and therefore often are used as decorative fitting and in medicine as implants [6,7]. Good tribological properties of thin layers enable excellent application [8];

firstly: PVD coated tools can be operated faster reducing cycle time and enabling the production of more components in less time, secondly: PVD layers reduce wear and pickup reducing downtime due to tool replacement, finally: PVD layers reduce the need for cutting fluid, because PVD layers on the tools can be run dry or with limited amount of fluid [9].

2 Experimental material and experimental methods

The steel of type Vanadis 30 [10] was coated with AlTiN multilayer and nanocomposite layer nc-AlTiN/Si_3N_4 (signed nACo). Vanadis 30 – Super Clean (signed VA 30) is a cobalt alloyed high performace PM high speed steel. The cobalt addition of approx. 8.5% has a positive influence on the hot strength/hot hardness, temper resistance and modulus of elasticity. The material belongs to the group of high performance high speed steels with excellent abrasion resistance, good toughness and machinability. The AlTiN multilayer was deposited by ARC (planar cathodes) technology by using coating machine PL1000. The nACo layer was deposited by LARC (LAteral Rotating ARC-Cathodes) technology by using coating machine π80. Roughness of deposited layers is affected by surface state [11]. Roughness of the substrate is usually lower than the resulting roughness after deposition, because macroparticles developing during the technological process increase roughness of coated surface. This phenomenon may be prevented by both perfect preparation of the material before coating and adjustment of coating technology [12]. Following this purpose we used LARC technology. Roughness of studied layers deposited on test specimens was analysed by Atomic Force Microscopy (AFM) [13]. Hardness is the mechanical property of materials inevitable for resistance to wear, in our case in cutting applications [14]. Using the statistically significant set of data we determined microhardness HV of the relevant layers at load 0.5 N. Calotest is a suitable method providing information on configuration and their thickness. These characteristics are important to determination of resistance to wear [15]. Rotating steel ball of diameter approx. 25 mm produces a crater on the specimen surface, the so-called calotte which serves to determine the thickness of layers. This method provides a unique opportunity to observe continuous transition from layer to layer down to the substrate. Tribological properties were evaluated by standard Pin-on-disc test. The principle of Pin-on-disc test is the contact of pin (WC ball) with evaluated specimen placed on rotating disc which allows one to observe coefficient of friction at simultaneous wear of the investigated surface [16]. Test results depend on the loading force (L), relative rate (v) of movement of the ball and specimen, number of laps (N), specimen status and properties of the tested material [17]. Our measurements were carried out using a tribometer CSM HT at 20°C and 400 °C. Tribological test conditions are given in **Table 1**. The principal variables affecting friction and wear are rotational speed and applied load. The measurements were conducted using a tribometer CSM HT at 20°C and 400 °C.

Table 1 Conditions of tribological test

Parameters	
Pin	WC, Ø = 6 mm
Temperature T	20 °C, 400 °C
Rate v	4 $cm.s^{-1}$
Number of laps N	10 000
Load L	5 N
Path radius	2; 4; 6; 8 mm

3 Results and discussion

Figure 1 shows surface of AlTiNmulti and nACo layer depicted by AFM. The values of roughness are characterised by parameters Rq and Ra, as indicated **Table 2**.

Table 2 Values of roughness of deposited layers

Layer	Measured at 20 °C			Measured at 400 °C		
	Rq / Ra, total [µm]	Rq / Ra, min [µm]	Rq / Ra, max [µm]	Rq /Ra, total [µm]	Rq / Ra, min [µm]	Rq / Ra, max [µm]
AlTiNmulti	59.3 / 45.9	7.42 / 5.92	62.9 / 28.3	64.6 / 25.3	5.92 / 4.11	66.2 / 26.0
nACo	37.9 / 20.4	19.3 / 11.5	54.0 / 32.0	28.5 / 18.7	12.7 / 9.7	26.9 / 18.1

Rq – root-mean-square deviation of the profile, Ra – arithmetical mean deviation of the profile

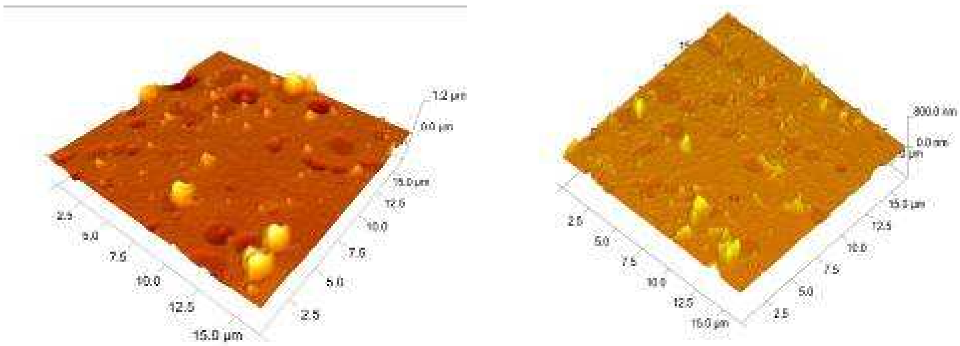

Fig.1 Roughness: a) AlTiN multi - ARC method, b) nACo – LARC method

The AlTiN multilayer was deposited by ARC technology the principle of which is evaporation of material from electrodes (4-flat electrodes placed in corners of the coating chamber) by means of low-voltage arc. The nanocomposite layer was deposited by modern LARC®–Technology (LAteral Rotating ARC-Cathodes). Improvement of this π-avantgarde technology is based on rotating cathodes and their lateral position. Application of this modern technology was reflected on the decline of macroparticles number and thus in decrease of surface roughness of the nanocomposite layer - nACo almost by 50% (Tab. 2). Decrease in roughness results in wear resistance inevitable for cutting tools in the working process [18]. Hardness measured by LECO LM 700 AT, using load of 0.5 N, reached 21.5 ± 2.5 GPa for AlTiN multilayer and 23.9 ± 0.7 GPa for nACo layer. The deposited coatings contributed undoubtedly to increased hardness because hardness of the base substrate before coating was approx. 12.4 ± 0.6 GPa.
Thickness of the layers determined by Calotest reached 2.63 µm AlTiNmulti; the thickness of one layer was about 0.2 – 0.25 µm. The thickness of nACo was 2.22 µm. **Figs. 2** and **3** show the calotte on the individual layers. In central part of the calottes one can observe exposed base material which enables to analyse the magnitude of damage to the layers following the wear. In our case, the results were favourable indicating good adhesion of layers because the pin did not penetrate into the base material after a specified number of cycles. The calottes had regular form and transition of layers was distinctive without failure. The base substrate was disturbed in the direction of sphere travel.
Results of measurement of Pin-on-disc test using a tribometer CSM HT at 20°C and 400 °C are presented in **Table 3**.

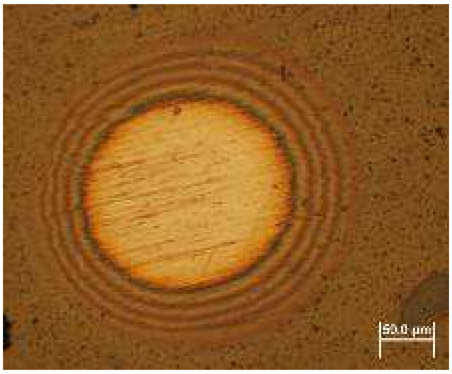

Fig. 2 Calotte of AlTiN multilayer

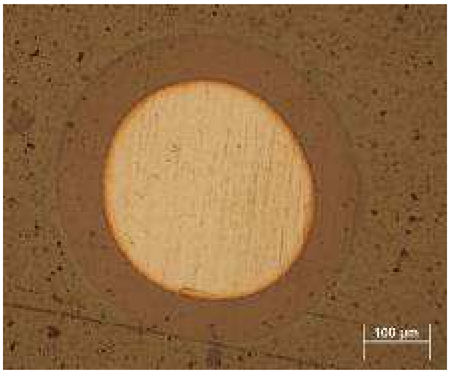

Fig. 3 Calotte of nACo layer

Table 3 Mean values of the friction coefficient for PVD layers

Layer	Path radius r [mm]	20 °C	400 °C
		Coefficient of friction	
AlTINmulti	2	0.672 ± 0.066	1.169 ± 0.059
	4	0.706 ± 0.063	1.242 ± 0.116
	6	0.729 ± 0.068	-
	8	0.789 ± 0.085	1.108 ± 0.287
nACo	2	0.677 ± 0.049	0.890 ± 0.171
	4	0.690 ± 0.061	1.045 ± 0.053
	6	0.693 ± 0.061	-
	8	0.713 ± 0.050	1.026 ± 0.073

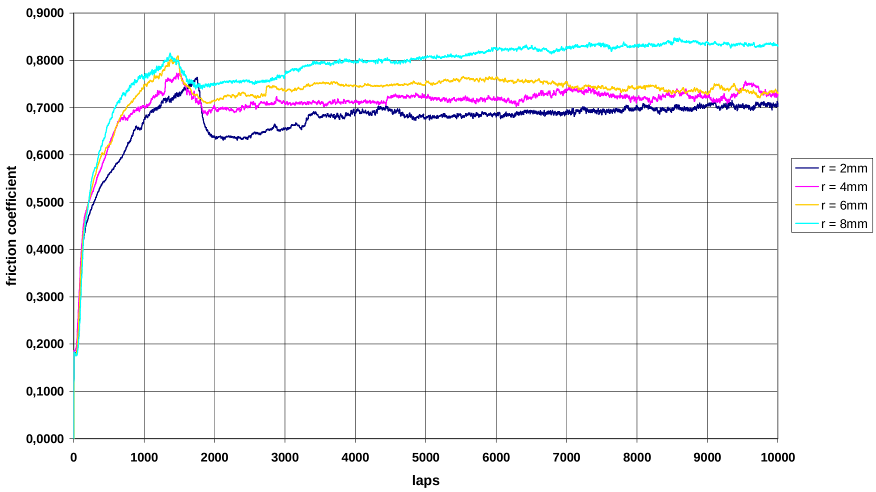

Fig. 4 Courses of the friction coefficient of AlTiN multilayer at 20 °C

Coefficients of friction for both systems and individual paths are summarised in Table 3 and graphical records of friction coefficient course are shown in Fig. 4-7. **Fig. 4** and **5** show the results of tribological test of AlTiN multilayer and nACo at 20 °C. Course of friction coefficient, **Fig. 4**, was stable after about 1500 laps for all path radius and values of coefficient were from 0.672 to 0.789 for AlTiN multi. Decrease of the friction coefficient of nACo layer, **Fig. 5**, after about 2500 laps for 4, 6 and 8 mm path radius and after about 4000 laps for 2 mm path radius caused the formation of sliding layer at the surface.

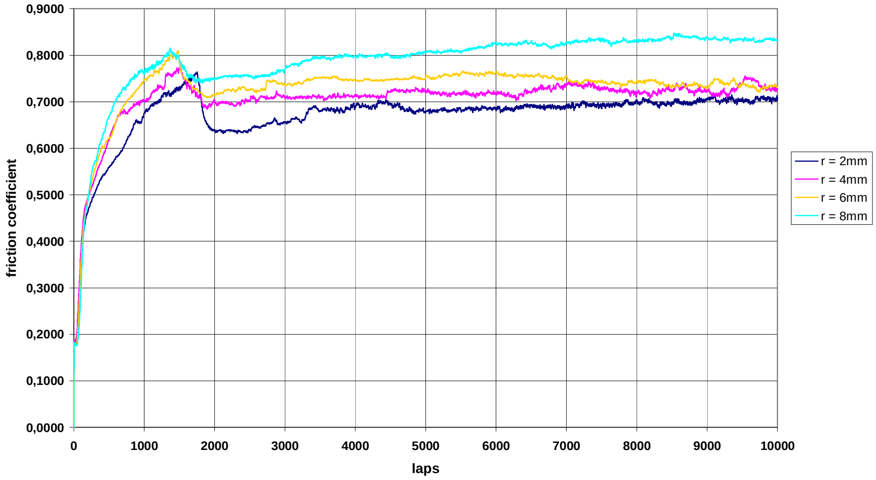

Fig. 4 Courses of the friction coefficient of AlTiN multilayer at 20 °C

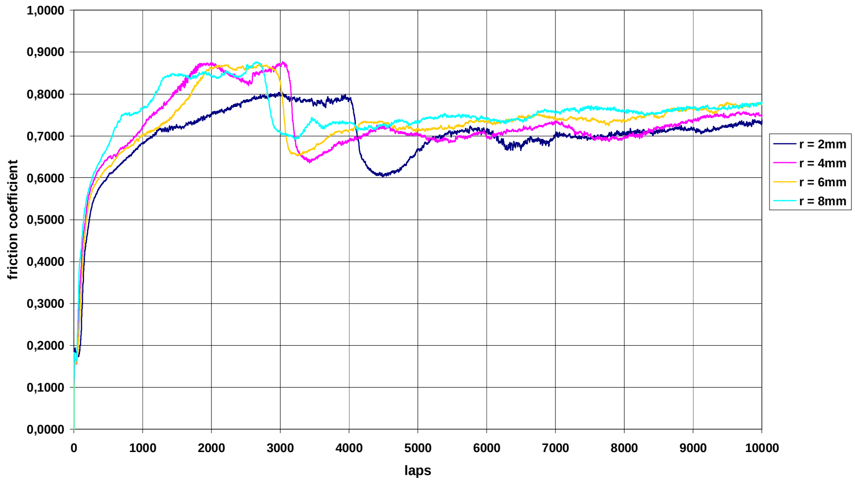

Fig. 5 Courses of the friction coefficient of nACo at 20 °C

In **Fig. 6** and **7** is documented character of the friction coefficient of tested layers at 400 °C. Growth of coefficient value at 400 °C relates with increased Al oxides. These oxides have worse tribological properties and they have loosened during wearing. Values of coefficient of nACo layer were less than tribological coefficient values of AlTiN, namely for 0.890 to 1.026. The measuring for 2 mm path radius was realised at the beginning of test; the measuring for 4, 6 and 8 mm path radius after 2 hours.

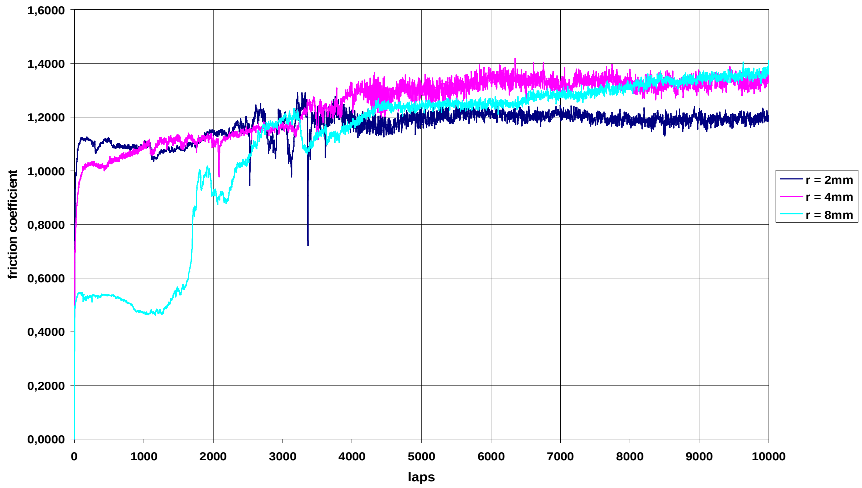

Fig. 6 Courses of the friction coefficient of AlTiN multilayer at 400 °C

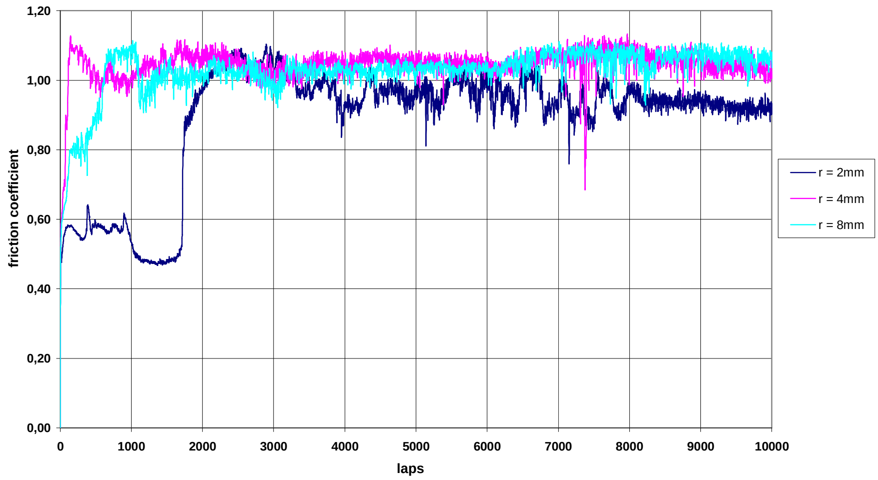

Fig.7 Courses of the friction coefficient of nACo at 400 °C

4 Conclusions

The tests performed and their analysis allowed us to draw the following conclusions:

- Application of modern LARC technology manifested itself by decrease in parameters of roughness of the nanocomposite layer nACo almost by 50%;
- Hardness was reached the following values at load 0.5 N: 21.5 ± 2.5 for AlTiN multilayer and 23.9 ± 0.7 GPa for nACo layer.
- Deposited layers contributed undoubtedly to higher hardness because hardness of the steel substrate before coating reached approx. 12.4 ± 0.6 GPa;
- Was determined thickness of layers; AlTiNmulti = 2.63.µm and nACo = 2.22 µm;
- Pin-on-disc tribological test shown the course of the friction coefficient for coated samples; at the higher temperature there is the oxide layer, which worsens surface quality. Values of friction coefficient of AlTiNmulti were for 0.672 to 0.789 at 20 °C and for 1.169 to 1.108 at

4000 °C for different path radius. Measured values friction coefficient of nACo layer ranged for 0.677 to 0.713 at 20 °C and for 0.890 to 1.026 at 400 °C for different path radius.

We can conclude that steels prepared by powder metallurgy are suitable for coating by thin hard layers which have excellent adhesion to the selected substrate. This fact allows us to assume that the mentioned coatings will ensure increase of lifetime of the studied steel in practical use.

Acknowledgement

Authors are grateful for the support of experimental works by project VEGA No.2/060/11.

References

[1] S. PalDey, S.C. Devi: Material Science and Engineering, 2003, A 342, p. 58-79.
[2] M. Hagarová, O. Bláhová, J. Savková: Acta Metallurgica Slovaca, Vol. 15, 2009, No. 4, p. 221-227.
[3] G.S. Fox – Rabinovich K. Yamomoto, S.C. Veldhuis, A.I. Kovalev, G.K. Dosbaeva: Surface and Coating Technology, Vol. 20, 2005, p. 1804-1813.
[4] J. Brezinová, J. Viňáš, A. Guzanová: Chemické listy, 105, 2011, p. 574-576 (In Slovak).
[5] D. Jakubéczyová, M. Hagarová, M. Vojtko: Acta Metallurgica Slovaca, Vol. 15, 2009, No. 1, p. 15-22.
[6] L.A. Dobzanski, K. Lukaszkowicz, D. Pakula, J. Mikula: Archieves of Materials Science and Engineering, Vol. 28, 2007, No. 1, p. 12-18.
[7] H.A. Jehn: Surface and Coating Technology, Vol. 125, 2000, No.1-3, p. 212-217.
[8] M. Hagarová, J. Savková, D. Jakubéczyová: Journal of Metals, Materials and Minerals, Vol. 18, 2008, No. 2, p. 25-31.
[9] [27.12.2011] www.valley-tool.com/coating.php.
[10] D. Jakubéczyová, P.Hvizdoš, M. Selecká: Powder Metallurgy Progress, Vol.10, 2010, No.3, p.146-156.
[11] D. Kniewald, J. Brezinová, A. Guzanová: Acta Mechanica Slovaca, Vol. 9, 2005, č. 3-A, p. 123-128 (In Slovak).
[12] V. Bačová, D. Draganovská: Materials Science, Vol. 40, 2004, No. 1, p. 125-131.
[13] J. Olofsson, J. Gerth, H. Nyberg, U. Wiklund, S. Jacobson: Wear, Vol. 271, 2011, No. 9-10, p. 2046-2057.
[14] A. Kimura, H. Hasegawa, K. Yamada, T. Suzuki: Surface and Coating Technology, Vol. 120-121, 1999, p. 438-441.
[15] J.L.Mo, M.H. Zhu: Tribology International, Vol. 42, 2009, No. 11-12, p. 1758-1764.
[16] R. Bidulský, M. Actis Grande, A. Zago, Z. Brytan, J. Bidulská: Archieves of Metallurgy and Materials, Vol. 55, 2010, No. 3, p. 623-629.
[17] K.N. Andersen, E.J. Bienk et al. Surface and Coating Technology, Vol. 123, 2000, No. 2-3, p. 219-226.
[18] P. Monka, K. Monková: Machined Surface Quality Improvement by using of special cutting tool. In.: Total Quality Management - Advanced and Intelligent Approaches 2011, Belgrade, Manufuture in Serbia, 2011, p. 393 – 396.