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Comparison of the PVD coatings deposited onto hot work tool steel and brass substrates

M. Polok-Rubiniec, K. Lukaszkowicz, L.A. Dobrzański*, M. Adamiak
Division of Materials Processing Technology, Management and Computer Techniques in Materials Science, Institute of Engineering Materials and Biomaterials, Silesian University of Technology, ul. Konarskiego 18a, 44-100 Gliwice, Poland
* Corresponding author: E-mail address: leszek.dobrzanski@polsl.pl

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ABSTRACT

Purpose: The aim of the research is the investigation of the structure and mechanical properties of monolayers CrN, TiN and multilayers TiN/TiAlN and Ti/TiAlN coatings deposited by PVD techniques onto the substrate from the X37CrMoV5-1 steel and CuZn40Pb2 brass.
Design/methodology/approach: The microhardness tests were made on the dynamic ultra-microhardness tester. Tests of the coatings' adhesion to the substrate material were made using the scratch test. The wear and friction tests were performed on a standard pin-on-disc device.
Findings: The monolayer PVD coatings deposited onto hot work steel and brass substrate demonstrate the high hardness, adhesion and wear resistance. The critical load L_{C2}, which is in the range 32-60 N, depends on the coating and substrate type. The friction coefficient for the investigated coatings is within the range of 0.33-0.75.
Practical implications: The investigation results will provide useful information to applying the PVD coating for the improvement of mechanical properties of the hot work tool steels and brass substrates.
Originality/value: It should be stressed that the mechanical properties of the PVD coatings obtained in this work are very encouraging and therefore their application for products manufactured at mass scale is possible in all cases where reliable, very hard and abrasion resistant coatings, deposited onto tools steel and brass substrate are needed.
Keywords: Thin&thick coatings; Mechanical properties

1. Introduction

The dynamical development of the industry poses higher and higher demands, especially in the area of the adjustment of their properties to the anticipated their operation conditions and applications. This regards, first of all, constructional materials, tool materials, copper alloys, etc. Achievement of the required high working properties is connected in most cases with the necessity of improvement of their manufacturing technologies, employment of novel manufacturing technologies or else modifications of the surface layer [1-3].

Service life of tools made from hot work steels (among others forging tools, moulds for light metals pressure die casting, rolls for copper hot rolling , mandrels, tools for hot cutting) for the sake their prices is an extremely essential thing in the context of production costs lowering and optimization. One of the most frequently applied method of tool life improvement is PVD technique [4-5]. Thin hard PVD coatings are today employed in vast number of applications for reducing friction and wear of tools and mechanical components [6-8].

Selection of the substrate material onto which the investigated coatings were deposited by PVD technique in the presented paper was not incidental either. Many elements of sanitary fittings, various holders and furniture are made in a traditional way from the cast or plastic formed brass, which is often coated with the galvanic methods, most often with nickel and chromium. This is connected with the high environmental and health hazards to their manufacturing staff. It turns out that brass, because of its good castability and machinability, remains still a willingly used material; however the high requirements pertaining to its properties stimulated employment of other methods, ecologically clean and giving a chance to obtain more diversified coating coloration and also more advantageous functional properties. Therefore, search is ongoing for other technologies that might meet the requirements connected with the good functional properties and their clean manufacturing technology. Coating deposition with the PVD method is one of them [9-11].

The aim of this work is the investigation of the mechanical properties of CrN, TiN and TiN/TiAlN, Ti/TiAlN coatings deposited by PVD techniques onto the substrate from the X37CrMoV5-1 steel and CuZn40Pb2 brass.

2. Investigation methodology

The examinations have been made on the specimens of hot work tool steel X37CrMoV5-1 (55 HRC, diameter 55 mm and thickness 4 mm) and brass CuZn40Pb2 (140 HB, 50×30 mm, thickness 3 mm) covered with the hard CrN, TiN and TiN/TiAlN, Ti/TiAlN coatings during the PVD process. To ensure a proper quality, the surfaces of the steel and brass specimens have been subjected to mechanical grinding and polishing (R_a=0,01 µm).

Experimental methodology was presented in [12, 13]. During the adhesion scratch tests of the coatings one has observed damages which P. Burnett [14] and V. Bellido-Gonzalez [15] divided as follows: spalling failure, buckling failure, chipping failure, conformal cracking, tensile cracking.

3. Discussion of results

As a result of the metallographic examinations made on the SEM it has been found out that the morphology of the investigated PVD coatings deposited onto hot work steel X37CrMoV5-1 and CuZn40Pb2 brass type is characterised by a significant inhomogeneity connected with the occurrence of multiple drop-shaped micro-particles on their surface and also with pits developed by falling out by some of these drops. The presence of these defects was observed in the largest scale in case of TiN and CrN monolayer coatings when the presence in TiN/TiAlN multilayer coating deposited onto steel substrate was the smallest one (Fig. 1). The results of this investigation correspond with the results of roughness and value of the friction coefficient (Table 1). Metallographic examinations of coatings fractures show that TiN coating (Fig. 2a) has compacted, columnar structure while the CrN coating (Fig. 2b) has a compacted submicrocrystalline structure. Examinations of the fracture surface of the Ti/TiAlN coatings indicate their laminar structure (Fig. 2c). It has been found out that the investigated PVD coatings deposited onto hot work steel X37CrMoV5-1 and CuZn40Pb2 brass type are characterised by a uniform thickness.

The roughness of the investigated PVD coatings ranges from 0.08 to 0.29 µm. The results of these measurements correspond with the metallographic examinations made on the SEM. The topography of the coatings influences the roughness, which is characterized by heterogeneity in the forms of cavities and elementary particles as well as a little smoothness of the surfaces of the investigated PVD coatings. The microhardness of the PVD coatings was made using a load 10 mN, making it possible to eliminate, to the greatest extent, the influence of the substrate on the obtained results. The microhardness ranges from 2400 to 3200 HV. The results of this investigation can be indicated the correlation between hardness and adhesion of the PVD coatings to the substrate material. The results of the microhardness tests and of the measurements of roughness are presented in Table 1.

The critical load L_{C2} were determined using the scratch method with the linearly increasing load („scratch test"), characterizing adhesion of the investigated coatings to the substrate, caused mostly by the adhesion and diffusion forces. The summary results are presented in Table 1

It has been found out, on the basis of on the determined L_{C2} (AE) values and on the developed failures metallographic examinations that multilayer TiN/TiAlN coatings have very good adhesion to the substrate from the hot work tools steels, whereas the CrN coatings adhesion reaches the lowest value. The damage of the coatings commences in all cases with the widespread coating spallation on both edges of the originating scratch. The difference consists in the location of these spalling

Table 1.
Summary results of the mechanical properties

Coating type	Substrate	Roughness, R_a [µm]	Thickness [µm]	Microhardness HV	Critical load L_{C2}, N	Friction coefficient µ
CrN	X37CrMoV5-1	0.09	2.2	2400	32	0.60
	CuZn40Pb2	0.15	3.6	2400	48	0.55
TiN	X37CrMoV5-1	0.18	1.9	2700	49	0.50
	CuZn40Pb2	0.29	2.4	2800	57	0.52
TiN/TiAlN×40	X37CrMoV5-1	0.08	1.8	3200	60	0.40
Ti/TiAlN×15	CuZn40Pb2	0.21	2.3	2900	40	0.42

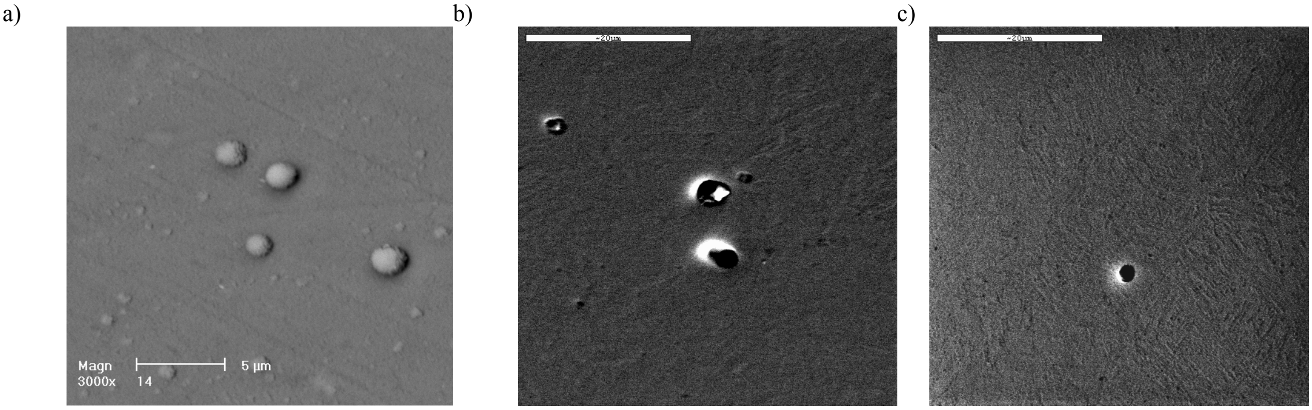

Fig.1. Topography of the PVD coatings: a) TiN deposited onto CuZn40Pb2 brass, and b) CrN, c) TiN/TiAlN×40 deposited onto hot work steel X37CrMoV5-1 substrates

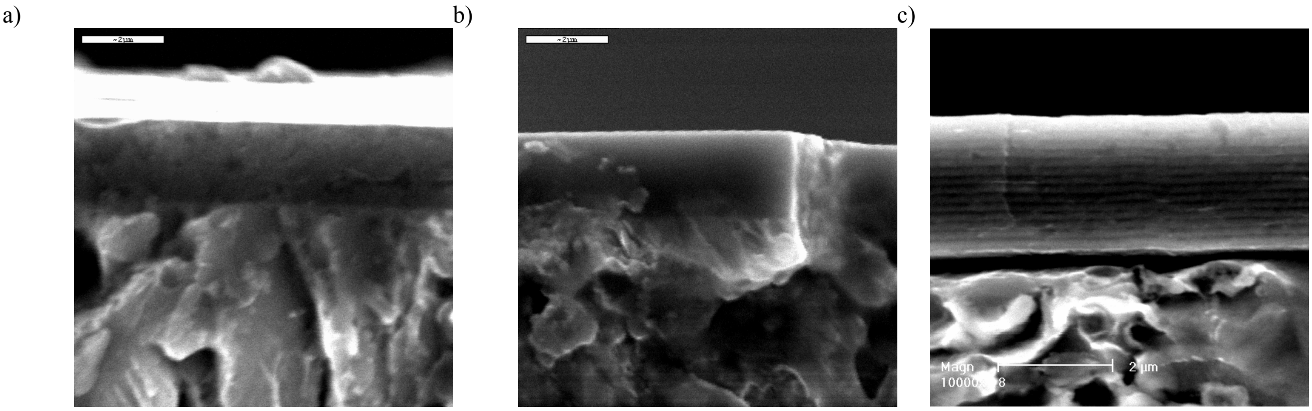

Fig.2. Fracture of the investigated PVD coatings: a) TiN, b) CrN deposited onto hot work steel X37CrMoV5-1, and c) Ti/TiAlN×15 deposited onto CuZn40Pb2 brass substrates

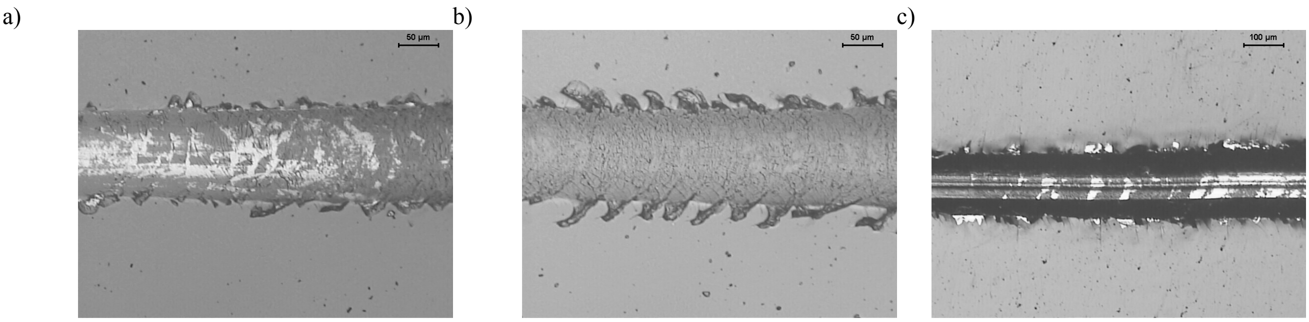

Fig.3. Characteristic failure of the investigated PVD coatings: a) TiN/TiAlN×40, b) CrN deposited onto hot work steel X37CrMoV5-1, and c) TiN deposited onto CuZn40Pb2 brass substrates

defects begin at the load value of about 45 N. Next, cracks and coating stretches, develop on the scratch bottom, and finally the total coating delamination on the scratch bottom takes place. The employment of the EDS analyser on the scanning microscope has let it to reveal, that in case of the TiN/(Ti,Al)N coating delamination occurs from the initially deposited titanium sublayer. In case of the TiN coating, the damage begins from numerous double-sided chips on the edges of the scratch combined with stretching on its bottom. Next there are flakes and conformal cracks connected with delamination. The analysis of the test results makes it possible to state that in case of the single-layer CrN coating the numerous spalling defects of the scratch edges begin at load of 21 N (Fig. 3b). Spalling defect at the edge gets deeper and next coating delamination occurs.

A weak adhesion of the CrN coating to the substrate may result from its relatively low hardness. As a result of the pressure of the indenter, the plastic deformation of the coating may take place as the softer and more elastic CrN coating undergoes a bigger deformation than the hard, multilayer TiN/(Ti,Al)N coating. Test results of the investigated PVD coatings adhesion to the substrate from the nitrided hot work tool steel correspond with the results of the wear test.

In case of the coatings deposited onto brass substrate good adhesion of the deposited coatings to the substrate should be connected with the existence of the transition layer [13]. This may be attested by the critical load L_{C2}, being in the range of 57-38 N (Table 2), depending on the coating type. Generally, in most cases of the investigated coatings deposited with the PVD technique, the first symptoms of coating damage are arc shaped cracks caused by tension and spalling, occurring at the bottom of scratch developing during the adhesion test (Figs. 3c). Minute chipping occurs on scratch edges in rare cases. Along with load increase, semicircles develop, connected with conformal cracking, leading to separation of layers and chipping, due to which local delamination occurs. In fracture test of brass with coatings put down, carried out after cooling in liquid nitrogen, in no case delaminations were revealed along the substrate-coating separation surface, which indicates to good adhesion of coatings to brass. However, in all investigated cases nearly total delamination occurs at maximum load, which can be caused by significant differences of the mechanical and physical properties, occurring between the soft material and hard coating.

The pin-on-disc abrasion resistance tests were carried out to determine fully the functional and working characteristics of coatings deposited onto the brass substrate by PVD process. The investigated coatings were subjected to the pin-on-disc tribological test carried out at room temperature (20˚C). Changes of the friction coefficient values between the corundum ball and the examined test piece were recorded during the tests. The analysis of the friction coefficient value changes of the investigated test pieces makes it possible to state that at the assumed experiment conditions the friction coefficient changes to about 0.4 for the TiN/TiAlN coating and to about 0.6 for the CrN after 1000 test piece revolutions at the room temperature (Table 1).

4. Conclusions

Basing on the investigation results the following conclusions were arrived at:

- the deposited PVD coatings onto the X37CrMoV5-1 steel and CuZn40Pb2 brass substrate are characterized by an identical thickness as well as a tight adhesion to the substrate material and a close construction without noticeable discontinuities in the form of delaminations or pores.
- the hardness of the investigated coatings is between 2400 HV for the CrN coatings and 3200 HV for the TiN/(Ti,Al)N coatings. The hardness of the examined PVD coating correlates with their adhesion to the substrate material.
- the investigated coatings demonstrate good adherence to substrate, which is decided not only by adhesion but also the interlayer between the coating and the substrate, developed as a result of diffusion and because of action of high energy ions causing mixing of elements in the interface zone.
- the coatings surfaces morphology is characterized by significant inhomogeneity connected with occurence on the surface of numerous drop shaped or nearly spherical particles, causing rise of the R_a roughness parameter values to 0.08÷0.29 µm and of the friction coefficient in the range of 0.40÷0.60.

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