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Mechanical properties of the PVD gradient coatings deposited onto the hot work tool steel X40CrMoV5-1

K. Lukaszkowicz [a], L.A. Dobrzański [a,*], M. Pancielejko [b]
[a] 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
[b] Institute of Materials Science and Technology, Technical University of Koszalin, ul. Raclawicka 15-17, 75-620 Koszalin, Poland
* Corresponding author: E-mail address: leszek.dobrzanski@polsl.pl

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Properties

ABSTRACT

Purpose: The aim of the research is the investigation of the mechanical properties of gradient coatings deposited by PVD technique (cathodic arc evaporation method) onto the substrate from the X40CrMoV5-1 hot work steel.
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 hard PVD gradient coatings deposited by cathodic arc evaporation method demonstrate the high hardness, adhesion and wear resistance. The critical load L_{C2}, which is in the range 46-59 N, depends on the coating type. The friction coefficient for the investigated coatings is within the range of 0.30-0.90.
Research limitations/implications: In order to evaluate with more detail the possibility of applying these coatings in tools steel, further investigations should be concentrated on the determination of the mechanical and tribological properties of the coatings.
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 substrate are needed.
Keywords: Mechanical properties; Thin&thick coatings

1. Introduction

A constant desire of tool material designers for at least several decades is the will to prepare and make an ideal tool material which would show a high ductility and a maximum possible resistance to wear in working conditions. Normally such a combination is impossible to obtain. Thus there have been various attempts made to solve, at least partly, the problem, by creating layer structures using, among others, methods of thermo chemical treatment, by making composite materials and single-layer coating using CVD and PVD methods, as well as overlaying welding [1-6]. Each of these methods reveals restrictions related to an inappropriate thickness of a surface layer, and especially with problems related to inappropriate adhesion of a manufactured layer, or excessively big stresses between the surface layer and a substrate what is often a cause for an accelerated layer cracking or chipping, especially in conditions of superposition of internal structure stresses and external stresses resulting from loads in working conditions.

One ascribes a solution in placing gradient coatings on the material tool substrate, assuring a suitably high resistance to wear in tool working conditions and a ductility of the core as well as a stress relaxation between particular coating layers and also between a gradient coating and the substrate of the tool material [7-11]. Functional gradient coatings create a new generation of coatings where properties and the structure change gradually. In many cases there is a leaping properties' difference between the coating and the substrate, bringing about in this area a concentration of stresses alike during manufacturing as well as tool operation. This causes a fast degradation in the area consisting in cracks and delamination of the coatings. An application of functional gradient coatings makes a possible solution to the problem. An area of applications of gradient coatings, because of their peculiar properties such as resistance to high-temperature oxidation and erosion as well as resistance to wear, is manufacturing modern cutting tools. Cutting tools may be used in many other deployments including the application for a protection from a high-temperature oxidation.

The aim of this paper is to examine the structure and mechanical properties of the gradient coatings deposited with PVD technique onto a hot work tool alloy steel substrate X40CrMoV5-1.

2. Investigation methodology

The examinations have been made on the specimens of hot work tool steel X40CrMoV5-1 (56 HRC, 30×5 mm) covered with the hard gradient coatings during the PVD process. To ensure a proper quality, the surfaces of the steel specimens have been subjected to mechanical grinding and polishing (R_a=0,03 µm). The process of the coatings' deposition has been made in the device based on the cathodic arc evaporation (CAE) method.

Experimental methodology was presented in [2, 5]. During the adhesion scratch tests of the coatings one has observed damages which P. Burnett divided as follows [12, 13]: spalling failure, buckling failure, chipping failure, conformal cracking, tensile cracking.

3. Investigations results

As a result of the micro-hardness tests done one has stated that the X40CrMoV5-1 steel substrate without a coating shows the hardness of 56 HRC. The deposition of the PVD coatings onto the specimens causes the growth of the hardness of the surface layer contained in the range from 30 to 33 GPa. The highest hardness of 33 GPa has been noted in the case of TiAlN coating while the smallest hardness of 33 GPa is characteristic for TiCN coating (Table 1).

The examined X40CrMoV5-1 steel specimens of the adequate quality of the surface, prepared for coatings' deposition through grinding and polishing using the diamond suspension, show roughness of R_a=0.03 µm. The deposition of the coatings causes a significant increase of roughness R_a up to 0.13÷0.22 µm (Table 1) depending on the kind of the coating.

The values of the critical load L_{C1} and L_{C2} characterized by adhesion of the examined coatings to the X40CrMoV5-1 steel substrate, caused mainly by the forces of adhesion, have been determined using the scratch test with a linear growing load.

The first critical load L_{C1} corresponds to the point at which first damage is observed; the first appearance of microcraking, surface flaking outside or inside the track without any exposure of the material substrate – the first cohesion-related failure event (Fig. 3a, 4a). This first damage has the shape of an interfacial shell-shaped spallation. Note that L_{C1} corresponds to the first small jump on the acoustic emission signal, as well as on the friction force curve (Fig. 2 ,3). The second critical load L_{C2} is the point at which the damage becomes continuous and complete delamination of the coating start; the first appearance of cracking chipping, spallation and delamination outside or inside the track with the exposure of the material substrate – the first adhesion-related failure event (Fig. 3b, 4b). After this point, all of the acoustic emission, friction force signals become noisier [14, 15].

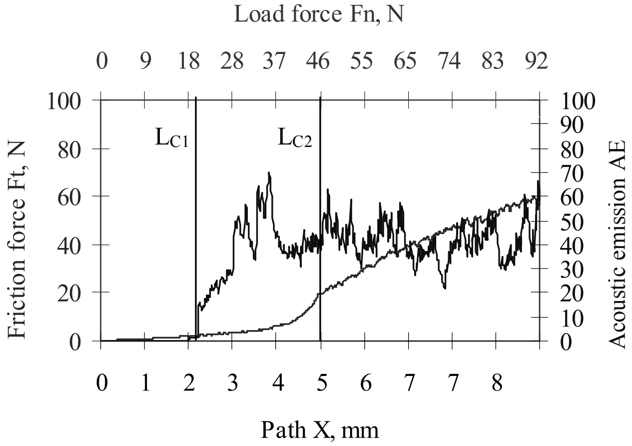

Fig. 1. Diagram of the dependence of the acoustic emission (AE) and friction force Ft on the load for the X40CrMoV5-1 steel with the gradient AlSiCrN/CrN coating

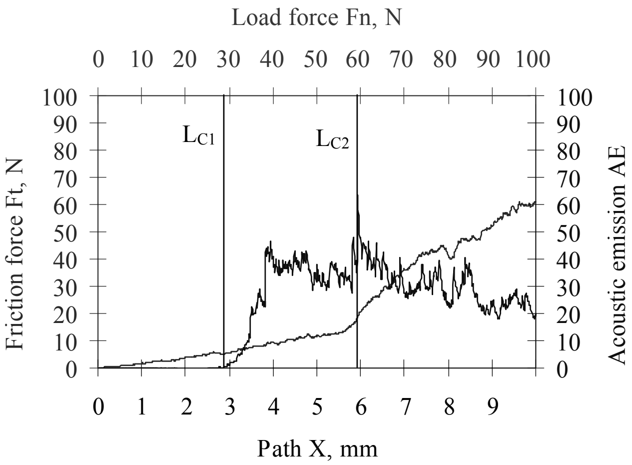

Fig. 2. Diagram of the dependence of the acoustic emission (AE) and friction force Ft on the load for the X40CrMoV5-1 steel with the gradient TiCN coating

Table 1.
The characteristics of the tested coatings

Coating	Thickness [μm]	Roughness [μm]	Microhardness [GPa]
TiAlN	2.8	0.13	33
AlSiCrN/CrN	2.1	0.20	32
TiCN	4.2	0.22	30

Table 2.
Comprehensive arrangement of mechanical properties of coatings

Coatings	Critical load L_{C1} [N]	Critical load L_{C2} [N]	Friction coefficient			
			pin-on-disc		scratch test	
			initial	final	initial	final
TiAlN - gradient	19	46	0.70	0.90	0.13	0.63
AlSiCrN/CrN - gradient	25	46	0.45	0.55	0.12	0.65
TiCN - gradient	28	59	0.30	0.35	0.21	0.62

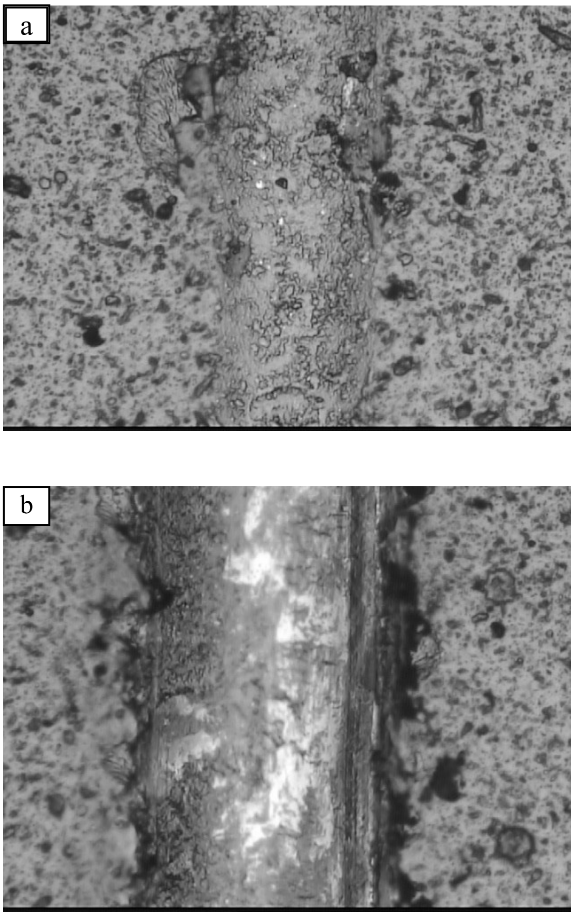

Fig. 3. Scratch failure pictures of the gradient AlSiCrN/CrN coating on X40CrMoV5-1 steel substrate at: (a) L_{C1}, (b) L_{C2}

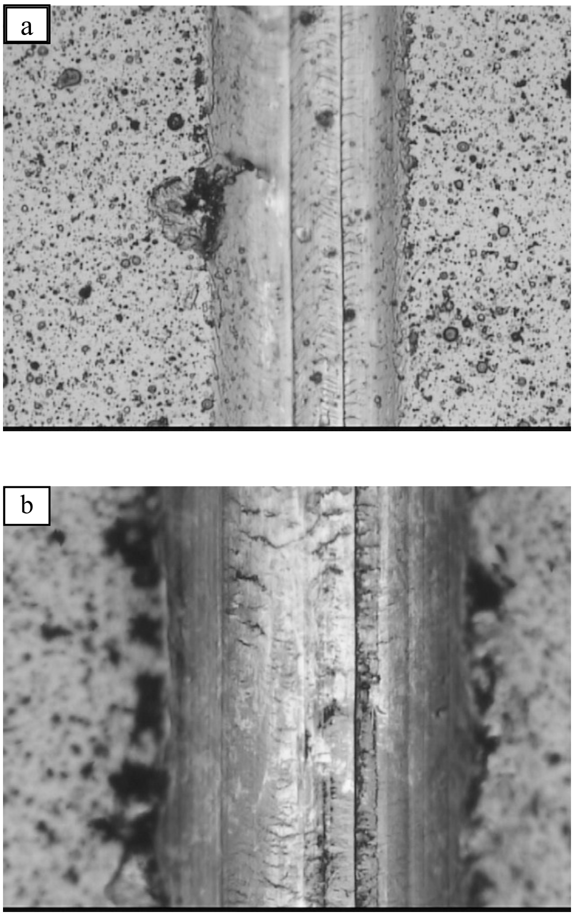

Fig. 4. Scratch failure pictures of the gradient TiCN coating on X40CrMoV5-1 steel substrate at: (a) L_{C1}, (b) L_{C2}

A comprehensive arrangement of the tests' results have been presented in Table 2.

To establish the character of the damage responsible for the increase of acoustic emission intensity, the examinations of the scratches that arose during the test have been made using the light microscope coupled with a measuring device, thus determining the value of the L_C critical load on the basis of metallographical observations. In the case of the examined coatings one has stated that the biggest value of the critical load of L_{C1}=33 and L_{C2}=59 N shows the TiCN coating whereas the smallest L_{C1}=19 and L_{C2}=46

N value show the AlSiCrN/CrN and TiAlN coatings.

In the first stage of the scratch test there appear microcracks and flakes on the edges of the scratch when the increase of the load reaches 19÷25 N (L_{C1}) which are a signal of a cohesive failure inside the examined coatings as a result of the substrate deformation caused by the pressure of the diamond penetrator. Along with a further increase of the load appear first wedge spallations, developing laterally to the penetrator's movement. Further increase of the load of up to about 46N leads to damages that characterize bilateral coating spallations on the edges of the scratch and a local delamination inside the scratch (L_{C2}) which, in the closing part, leads to the intensification of spallations and a band, partial delamination of the coating. One can many a time observe cracks caused by spreading and recurring spallation of the coating. The smallest number of damages is a feature of TiCN coating, for which insignificant one-sided spallations have been observed in the first part of the scratch after exceeding the Lc1 critical load. In all the tested cases, even at the biggest load, there is not a full delamination of any of the examined coatings.

As a result of tests done of tribological PVD coatings deposited onto the X40CrMoV5-1 steel substrate, for a number of cycles between 2700 and 7000, extensive adhesive damages of the coatings have been noticed in points of contact with the counter-specimen. A number of damages in the case of TiAlN coating is smaller that the remaining PVD coatings. A total delamination of this coating from the substrate has not been noted.

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In the case of the investigated coating the value of the friction coefficient varies depending on the number of cycles. In the case of the TiAlN coating, the initial value of the friction coefficient is 0.3, which next increases up to a value of 0.35 at the end of the test. For the remaining, in turn, PVD coatings the friction coefficient reaches the value of 0.50÷0.70 at the beginning of the test, and next stabilizes, reaching the value of 0.60÷0.90 depending on the kind of coating (Table 2).

4. Conclusions

The carried out adhesion investigations of the coatings using the scratch test reveal cohesive and adhesive properties of the examined coatings deposited onto the hot work, tool alloy steel X40CrMoV5-1. It has been stated, on the basis of the above examinations, that the critical load of L_{C2} is between 46÷59 N. The biggest value of the critical load has been obtained for the TiCN coating.

The deposition of the coatings with CAE method causes the increase of the roughness parameter Ra to 0.13÷0.22 μm in comparison with the X40CrMoV5-1 steel substrate prepared for the deposition of coatings, whereas the friction coefficient connected with the roughness is between 0.30÷0.90. A correlation between the increase of the roughness value and the friction coefficient has been noticed.

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