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Structure and properties of wear resistance PVD coatings deposited onto X37CrMoV5-1 type hot work steel

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Abstract: The paper presents results of the investigation of the structure, mechanical properties and tribological tests of CrN, TiN, TiN/(Ti,Al)N PVD coatings deposited onto X37CrMoV5-1 type hot work steel. Basing on the results of metallographic examinations of microstructure it was shown that TiN, TiN/(Ti,Al)N coatings have compact, columnar structure, while CrN coating has compact submicrocrystalline structure. We found that the TiN monolayer coating demonstrates the lowest wear at certain conditions at both room and elevated temperatures which can be connected with its good adherence to the substrate materials.

Keywords: PVD coatings, Structure, Adhesion, Wear resistance, X37CrMoV5-1

1. INTRODUCTION

Metalworking industries have shown interest to improve tools used in hot-working process: metal die casting, hot extrusion and hot forging [1,2,3]. 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 working) for the sake of their prices is an extremely essential issue in the context of lowering the production costs and its optimization. One of the most frequently applied method of tool life improvement is PVD technique [4,5].

Thin hard coatings are employed today in the vast number of applications for reducing friction and wear of tools and mechanical components. PVD coatings have also been used for selected hot-working processes. The majority of results have been obtained with metal die casting of non-ferrous metals (Al, Mg, Cu and Zn) and alloys. Relatively little data is available for the hot extrusion and forging processes [6,7].

The goal of this investigation is to determine the usefulness of the CrN, TiN, TiN/(Ti,Al)N PVD coatings deposition to improve wear resistance of tools made from hot work steels, particularly from the X37CrMoV5-1 type.

2. EXPERIMENTAL PROCEDURE

TiN and CrN coatings were prepared in BALZERS BAI 730 deposition system by ion plating PVD process at 450˚C temperature, while (TiN/TiAlN) coating was deposited by reactive sputtering in a Sputron (Balzers) plasma-beam-sputtering apparatus at the temperature 200°C. All coatings were deposited onto X37CrMoV5-1 type hot work steel substrates. The samples in the form of disc (diameter 55 mm and thickness 5 mm) were quenched at 1020˚C and tempered at 550˚C to hardness 55 HRC.

The specimens with the notch cut were cooled in liquid nitrogen before breaking in order to observe their structure on transverse fractures on the Opton DSM 940 SEM. Evaluation of the adhesion of coatings to the substrate was made using the scratch test, the test were made by the CSEM REVETEST scratch tester. The critical force at which coating failures appear, called the critical load L_c, was determined basing on the acoustic emission AE registered during the test and microscope observations for five critical forces: L_{c3} – flaking on the scratch edge, L_{c4} – coating partial delamination, L_{c5} – coating total delamination and $L_c(F_t)$ – sudden increase of the scratching force. The character of the defects was determined basing on observation performed on the scanning electron microscope Opton DSM 940. Wear resistance tests with the pin-on-disk method were carried out on the CSEM THT (High Temperature Tribometer) device at the room temperature and at the temperature of 500˚C. The Al_2O_3 corundum ball of the 6 mm diameter was used as counter-specimen. During the pin-on-disk test carried out at the room temperature the stationary ball was pressed with the load of 7.0 N to the disk rotating in a horizontal plane. The rotational speed of the disk with the specimen was 80 cm/s, friction radius was 15 mm, and the number of rotations was 7500. During the test at the temperature of 500˚C, the friction radius was changed from 15 mm to 18 mm, leaving other test parameters unchanged, as in the test made at room temperature.

3. RESULTS AND DISCUSSION

Metallographic examinations of coatings fractures show that the TiN, TiN/(Ti,Al)N coatings have the compact, columnar structure while the CrN coating has the compact submicrocrystalline structure. Examinations of the fracture surface of the TiN/(Ti,Al)N coatings indicate their laminar structure. It was found out that the investigated PVD coatings deposited onto X37CrMoV5-1 type hot work steel are characteristic of the uniform thickness.

Critical loads L_c characterising adhesion of the investigated coatings to the substrate from the hot work tool steel, were determined during the scratch test with the increasing load. The values of the critical loads for the particular coatings are presented in Table 1.

Table 1.
Critical loads for investigated coatings

Coating type	Type of defect/Force [N]				
	L_c (AE)	L_{c3}	L_{c4}	L_{c5}	L_c (F_t)
CrN	37	32	77	87	91
TiN	25.5	19.4	39	82	80.1
TiN/(Ti,Al)N	10.75	12.8	32.5	69	68.6

The CrN coatings demonstrate a very good adhesion to the substrate, next come the TiN ones, and the least advantageous adhesion was observed for the multilayer TiN/(Ti,Al)N coating. The coating failure mechanism in all cases begins from the numerous spallings on both edges of the developed scratch. The difference is in the location of these spallings. In case of the TiN/(Ti,Al)N coating, spallings start from the load as low as 13 N. Then cracks and stretches develop at the scratch bottom, and the spalling process at the scratch edge develops further, and finally total coating delamination occurs at the scratch bottom. Analysis of the results justifies a statement that in spite of the big differences in critical loads, depending on the evaluation criterion assumed, the general trend remains the same. Spalling begins with the monolayer TiN coatings at the load value of about 20 N, and with the multilayer CrN ones at about 32 N load value.

The investigated coatings and the substrate material were examined using the pin-on-disk test to determine their wear resistance; the test was carried out at the room temperature and at the temperature elevated to 500˚C. Changes of the friction coefficient value between the corundum ball and the tested specimen were recorded both for the room temperature and for the temperature of 500˚C. Analysis of the friction coefficient changes of the examined specimens indicate that in the assumed experiment conditions, the friction coefficient for the specimen coated in the PVD process changes in the range from about 0.45 (TiN) to about 0.7 for the TiN/(Ti,Al)N and the CrN coatings, in case of the tests carried out at the room temperature. Results of the tests carried out at the temperature of 500˚C revealed that the friction coefficient for the coated specimens was 0.55 for TiN, 0.6 for CrN, and 0.7 for the TiN/(Ti,Al)N coating. Only the TiN coating, as the only one from all tested coatings does not change the friction coefficient value during the entire test. The TiN/(Ti,Al)N and CrN coatings change their friction coefficient values after the initial test stage, which can be connected with their partial or total failure mechanisms, revealing values close to the ones for the uncoated steel in case of the CrN coating, or higher values in case of the partial failure which occurs in case of the TiN/(Ti,Al)N coating.

The quantitative evaluation of the surface wear of the examined specimens due to friction was carried out basing on measurements of the wear track profiles for the TiN, CrN, and TiN/(Ti,Al)N coatings deposited on the substrate made from the X37CrMoV5-1 hot work alloy tool steel, in four orthogonal directions, every 90˚. The average volume of the material removed due to friction of the corundum ball with the specimen surface was calculated using the known wear track length. The average volume of the material removed during the tribological wear was calculated using the formula:

$$V = P \times S \ [mm^3] \tag{1}$$

where: V – average volume of the material worn out due to the friction, P – average area of the removed material [mm^2], S – track length 2Πr [mm]

Measurement results of the removed material volume are presented in Table 2. One can state, basing on the wear measurement results collected for the specimens examined at the room temperature, that the highest wear resistance has the TiN coating.

Table 2.
Comparison of volume of materials removed during tribological wear

Coating type	Volume of materials removed V[mm^3]	
	Room temperature, 20˚C	Elevated temperature, 500˚C
CrN	0.05181	0.2854
TiN	0.0058875	0.043803
TiN/(Ti,Al)N	0.049455	0.067824

The change of the test temperature to 500˚C results, in each case, in the about five-fold increase of the wear intensity. However, the TiN monolayer still demonstrates its highest wear resistance. Wear resistance of the TiN/(Ti,Al)N coating has grown, and the CrN coating was the worsted.

Measurements of the wear track width were made basing on observations carried out on the light microscope; it was found out that the width increases with the test temperature increase and in case of the material with no anti-wear coating, tested at room temperature, it is about 0.3 mm, and at the temperature of 500˚C it is about 0.60 mm [2]. Deposition of the TiN coating results in decreasing the wear width to about 0.18 mm and about 0.45 mm for the tests carried out at the room temperature and at the elevated one respectively. Results of these measurements correspond with the removed material volume measurements made during the pin-on-disk tests and shows that the lowest wear at certain conditions in both room and elevated temperatures shows TiN monolayer coating.

4. CONCLUSION

The goal of this investigation is to determine usefulness of CrN, TiN, TiN/(Ti,Al)N PVD coatings deposition in order to improve wear resistance of tools made from hot work steels, particularly X37CrMoV5-1 type one. Basing on the metallographic examinations of coatings fractures one can state that TiN, TiN/(Ti,Al)N coatings have compact, columnar structure while CrN coating has compact submicrocrystalline structure and multilayer TiN/(Ti,Al)N coatings are characterised by laminar structure, all of them with a uniform thickness. Moreover it was found that the adhesion of the monolayer TiN, multilayer TiN/(Ti, Al)N, and monolayer CrN coatings to the substrate from the X37CrMoV5-1 hot work tool steel changes significantly depending from the assumed criterion; however the general trend remains. The CrN coating has the best adhesion, and the TiN/(Ti, Al)N coating demonstrates the worst adhesion.

Taking into account results of measurements one can state that the lowest wear at certain conditions in both room and elevated temperatures shows the TiN monolayer coating what can be connected with their good adherence to the substrate materials. On the other hand the CrN monolayer coating demonstrate the worst wear resistance at the same condition most probably because of relatively low hardness when moderate wear resistance demonstrate multilayer TiN/(Ti,Al)N coating.

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