Vol. 41, No. 1 (2019) 43-49, DOI: 10.24874/ti.2019.41.01.05

Tribology in Industry

www.tribology.rs

RESEARCH

# Increasing Tribo Unit Wear Resistance with the Ion-Plasma Coating

Ye. Ventsel[a], D. Glushkova[a], O. Orel[a], O. Shchukin[a], N. Saienko[a]

[a] *Kharkiv National Automobile and Highway University, Yaroslava Mudrogo st, 25, Kharkiv, Ukraine.*

Keywords:

*Wear*
*Wear resistance*
*Ion-plasma coating*
*Ion bombardment*
*Abrasive*
*Antiwear properties*

Corresponding author:

*Oleksandr Shchukin*
*Kharkiv National Automobile and Highway University , Yaroslava Mudrogo st, 25, Kharkiv, Ukraine, 61002*
*E-mail:* alexhome88@gmail.com

ABSTRACT

*The mode and parameters of applying an ion-plasma coating to the surface of the working bodies are established. The thickness of the ion-plasma coating on the surface of the excavating parts is specified. It is found that the samples with the thickness of the ion-plasma coating of 4 μm have the greatest wear resistance. The metallographic characteristics of the material of the knives with the ion-plasma coating applied to their surface are determined.*



## 1. INTRODUCTION

Increasing wear resistance of the tribo units of various machine parts, despite certain achievements in this direction, is still an urgent task. This is especially true for tribo units that work in extremely harsh abrasive conditions (for example, excavating parts of the earth-moving machinery (EMM), whose wear makes up 0.15 mm/hour on the average [1]).

To increase tribo units wear resistance, it is not sufficient to increase the structural strength of tribo surfaces, since in most cases the wear due to the effects of abrasive particles occurs at a high speed [2].

One of the main properties affecting wear resistance is the hardness of tribo surfaces, however, there is no consensus among researchers in this respect. This is due to the fact that hardness is nothing else but a function of the change in the strength of interatomic bonds because of different stress concentrations with different types of treatment [3]. The use of lubricants (where it is possible under the conditions of operation), as a rule, does not completely solve the problem, since the mechanical and thermal loads on tribo units are constantly increasing in order to raise the productivity of machines.

## 2. MAIN HEADING

Determining the effect of the ion-plasma coating (IPC) of the $TiN$-$Cr_2N$ system on the tribo unit wear resistance by using the method of condensation of a solid substance under the conditions of ion bombardment

## 3. PROPOSED MEASURES

Today, the main methods of applying plasma wear-resistant coatings, which significantly improve the performance characteristics of materials of tribo surfaces, are the chemical deposition from a gaseous medium and condensation of a solid substance under the conditions of ion bombardment (CIB) [4,5]. The most rational method is CIB, whose main advantage is the possibility to control the temperature of the process (~300–800 °C). This allows applying coatings to the parts made of various materials [5]. Such a principle makes the presented method universal and dominant among the similar technologies that increase the operational characteristics of materials, in particular, their wear resistance.

However, this method has not been used so far for applying IPC to tribo surfaces operating without lubricants. At the same time, the use of the CIB method is of great interest due to the fact that it allows varying the composition of the coating and, as a result, obtaining corrosion- and wear-resistant layers with high strength characteristics and reliable adhesion with the base metal.

With regard to the above-mentioned facts, the urgent problem is to choose a rational composition and a mode of applying a coating, which would allow to solve the problem of increasing the insufficient resource of tribo units with minimal costs for the technology of applying the latter.

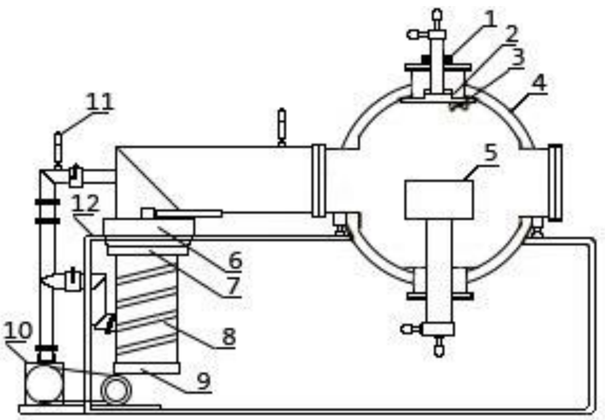
Thus, the following tasks of the laboratory experimental studies can be singled out, the solution of which will allow establishing the composition and the thickness of the coating required for increasing significantly the tribo unit wear resistance, as well as the effectiveness of this coating:

- selection and substantiation of the material of the IPC composition, as well as the technology of its applying to the tribo surface, for example, the excavating part (EP) of the EMM;
- determination of the spraying mode and the thickness of the IPC on the surface of the cutting elements, which would provide the EP operating in an abrasive soil without a lubricating material with the necessary physical and mechanical properties;
- determination of the effect of the selected coating on the wear of samples operating in an abrasive medium;
- determination of the metallographic characteristics of the material of the knives with the IPC applied to their surface.

### 3.1 Selection of materials for the ion-plasma coating

To apply the IPC, the Bulat-3T installation (Figs. 1 and 2) was used [5].

**Fig. 1.** General view of the Bulat-3T installation.




*1 - focusing coil; 2 - cathode; 3 - igniting electrode; 4 - chamber-anode; 5 - substrate; 6 - nitrogen trap; 7 - water trap; 8 - high vacuum unit; 9 - heater; 10 - forevacuum pump; 11 - manometric lamp; 12 – the system of the installation water cooling*

**Fig. 2.** Basic diagram of the Bulat-3T installation.

The method of applying the IPC includes two stages [6]:

1. Cleaning the surface of the sample with the subsequent heating and activation of the surface of the substrate by bombardment with ions of the deposited titanium.
2. Gradual deposition of the coating material with continuous ionic bombardment of the condensate in such a mode that would ensure formation of a film with the desired physical and mechanical properties.

As a result of the ion bombardment with ions and neutral electrons, gases are removed from the surface of the part, and it is also heated. Such a bombardment makes it possible to obtain an atomically clean surface of the part, due to which the rate of reactions of depositing the IPC material on the surface of the part increases significantly [6]. At the same time, heating that is associated with the ion bombardment, enhances the diffusion processes of the IPC interaction with the base metal [5]. In this case, the temperature of the substrate (tribo surface) is controlled by the Smotrich infrared pyrometer.

The above processes, which take place on the surface of the part, provide a relatively high adhesion of the coating [5,7].

The applied coating consists of the fusion of the alternating $Cr_2N$ five layers and TiN four layers. In the process of applying a multilayer coating, steel 65G is tempered (this is the base material of the EMM EP), that leads to a decrease in hardness to HRC30. After the heat treatment, the hardness of the substrate is restored and makes up HRC 50-54.

To select a composition of the IPC for the EMM EP, the laboratory tests were carried out on the SMC-2 friction machine (Figs. 3 and 4).

The tests on the SMC-2 friction machine were carried out according to the scheme “pad-roller” (Fig. 4), which simulates the operating conditions of the lower kinematic pairs.

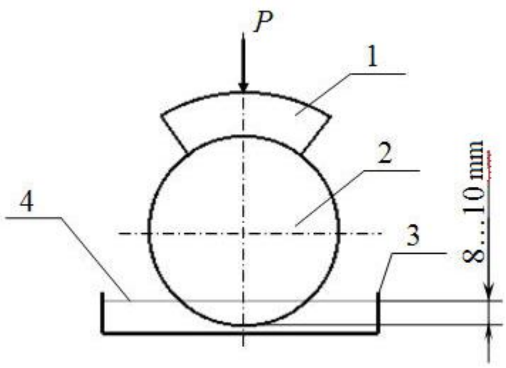
The characteristics of the samples were as follows:

- material - steel 65G (the chemical composition is given in Table 1);
- hardness of the steel used - 55HRC;
- cleanliness of surfaces –0.4 microns.
- Such indicators of the steel, as well as its chemical composition (Table 1) fully correspond to the material from which the real excavating parts of the EMM are made.

**Table 1.** The chemical composition of the rollers and pads made of steel 65G used during the tests.

| Part name | Element content [%] | | | | |
|---|---|---|---|---|---|
| | C | Si | Mn | Cr | Ni |
| Rollers and pads | 0.68 | 0.22 | 1.05 | 0.03 | 0.07 |

**Fig. 3.** General view of the SMC-2 friction machine.




*1 - pad; 2 - roller; 3 - cuvette; 4 - level of working fluid with abrasive (quartz sand)*

**Fig. 4.** Test diagram for the pad and roller on the SMC-2 friction machine.

The diameter of the rollers was 50 mm, the width - 12 mm, the width of the pad - 10 mm, the frequency of the roller rotation - 500 rpm. The rollers were dipped into a cuvette with a thick abrasive medium consisting of oil I-G-A-32 and fine-grained quartz sand with an average size of abrasive particles of 0.4 mm. The concentration of the abrasive (quartz sand) in oil was 30% by volume.

As shown by exploratory experiments and the experience of conducting similar tests on the SMC-2 friction machine, the load on the test samples should not exceed 200 N, otherwise tearing occurs on the tribo surfaces of the samples [8].

The mode of testing the samples, based on the above considerations, was as follows. Four batches of rollers and pads were subjected to breaking-in for 15 minutes under a load corresponding to the weight of the carriage. Then the tests continued for 4 hours and 45 minutes for each of the four batches of the pads under a load of 50 N (first batch), 100 N (second batch), 150 N (third batch) and 200 N (fourth batch).

The wear of the samples was determined by their weight loss during the test by weighing on the VLA-200g-M analytical balance with an accuracy of ± 0.0001 g with bringing the samples to constant weight. Each of the four batches of the rollers was divided into four groups:

- the first group - 8 rollers with HFC hardening at a temperature of 910 °C to a depth of 3–4 mm;
- the second group - 8 rollers with the TiN IPC;
- the third group - 8 rollers with the MoN IPC;
- the fourth group - 8 rollers with the TiN-$Cr_2N$ IPC.

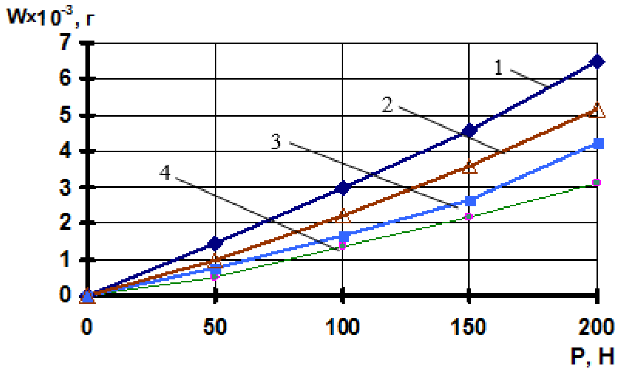
The choice of such coating materials is explained by the fact that these IPC are most often used for EMM parts in order to reduce their wear [4,9].

To obtain reliable results, the experiments were carried out eight times using new samples of each group and new portions of the abrasive medium. Such repeatability of experiments is stipulated by the experience of carrying out wear tests [10,11] and is calculated by an iterative method according to [12]:

$$n = \frac{t^2 \cdot \sigma^2}{\Delta^2}, \qquad (1)$$

where: $t$ – the norm that determines the guaranteed probability of the deviation of the average small sample from the average population; $\sigma$ - root-mean-square deviation; $\Delta$ - absolute error.

The test results on the SMC-2 friction machine are shown in Fig. 5.




*1 - steel 65G with HFC hardening; 2 - steel 65G with MoN coating; 3 - steel 65G with TiN coating; 4 - steel 65G with TiN-$Cr_2N$ coating*

**Fig. 5.** The dependence of wear W of the studied materials on the applied load P.

It follows from the graphs presented in Fig. 5 that the total wear of the samples after testing on the SMC-2 friction machine increases in direct proportion to the increase in the load on them. At the same time, the greatest wear under all loads occurs during testing of samples subjected to HFC hardening, and the lowest wear is observed in the HFC hardened samples, which were coated with the TIN-$Cr_2N$ IPC (2.78 times with the load of 50 N and 2.08 with the load of 200 N). It is noteworthy that as the load enhances, the difference in wear of all four batches of the samples increases.

The wear of the samples with the IPC of MoN and TiN under all loads is less as compared to the samples after HFC hardening, but bigger than that with the use of the TiN-$Cr_2N$ IPC.

Thus, it can be concluded that in order to increase the wear resistance of samples made of the hardened steel 65G, it is necessary to use the TiN-$Cr_2N$ IPC.

To establish the relationship between the modes of applying the TiN-$Cr_2N$ IPC, the characteristics of its microstructure, the physico-mechanical characteristics and the phase composition of the coating, metallographic, X-ray and X-ray microscopic studies were conducted.

To carry out these studies, polished sections were made, whose plane was located at an acute angle to the sample surface. Such a choice of the shape for these sections is explained by the fact that the surface layer has a relatively small thickness, and for a more detailed study of the structure and phase composition of the coating, this type of slanting thin sections is used [5]. To make such sections, diamond wheels were used, and the cutting was carried out from the coating to the substrate. Otherwise, the film of the coating was detached due to the occurrence of tensile stresses when the instrument touched the sample surface.

The metallographic studies were performed using the microscope MIM-8 with magnifications of 500, 1000, followed by photographing the image. In this case, metallographic sections were obtained by polishing with a diamond paste without the use of a cooling fluid. Not using the latter can be explained by the fact that abrupt cooling of the surface of the sections may affect the microstructure of the coating itself, and this, in turn, may have a negative impact on the results of metallographic studies. At the same time, to identify the microstructure of steel 65G, the polished sections were chemically etched in a 3% alcoholic solution of nitric acid (nital).

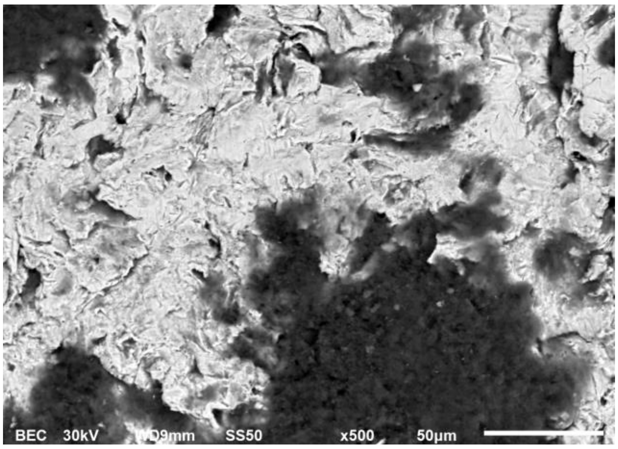



**Fig. 6.** Detachment of the TiN-$Cr_2N$ coating with the thickness of 7 microns.

As a result of the metallographic studies, it was found that the TiN-$Cr_2N$ coating had the best adhesion at a thickness of 2 to 5 microns. Otherwise, there was a violation of the integrity of the surface layer. As can be seen from Fig. 6, with a coating thickness of more than 5 microns in the process of wear, its detachment is observed.

The laboratory tests of the fragments of a grader knife with the TiN-$Cr_2N$ coating with the thickness of 1 micron showed, that it was destroyed during the first few hours of operation (Fig. 7).

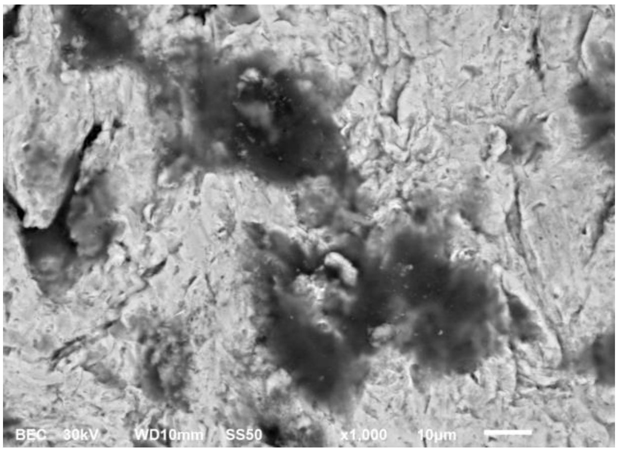


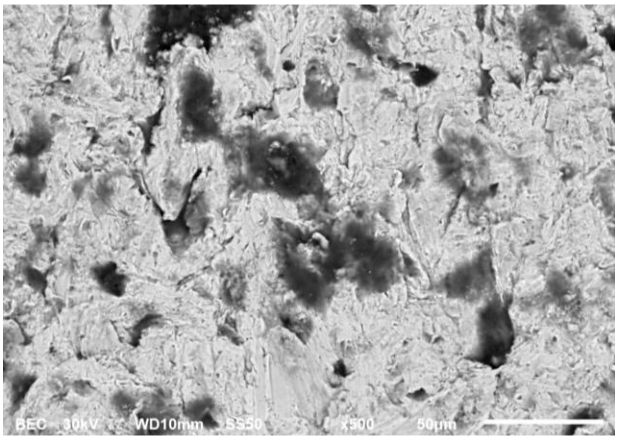

**Fig. 7.** The destruction of the TiN-$Cr_2N$ coating with the thickness of 1 micron.

In addition, as was shown above, the coating of the TiN-$Cr_2N$ system was applied to the samples under the modes presented in Table 2.

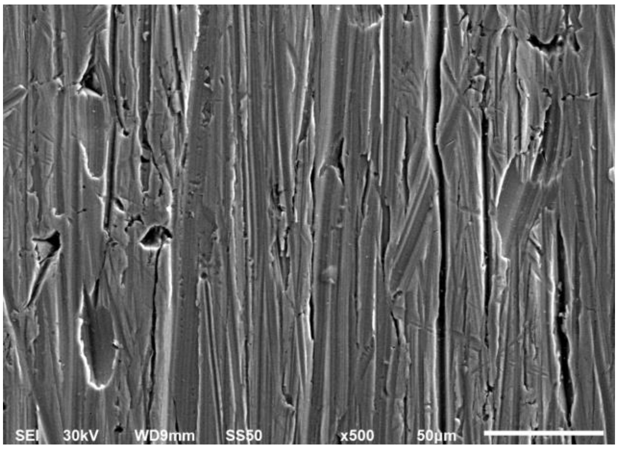
As can be seen from Fig. 8, such a coating can significantly smoothen surface irregularities, which can act as stress concentrators. In these photographs, the coating looks like a light strip, which has a clear border with the steel and is not etched by nital.

**Table 2.** Modes of coating of the TiN-Cr2N systemTiN–$Cr_2N$ [3].

| Emission cathode material | Current on Cr, A | Current on Ti, A | Voltage U, B | Current I, A | Pressure P, Pa | Time of deposition t, min |
|---|---|---|---|---|---|---|
| 1st stage: purification, warming and activation by chrome ions | | | | | | |
| Chrome | 80 | – | 90 | 2 | 1.33 | 7 |
| 2nd stage: coating sputtering in a nitrogen atmosphere | | | | | | |
| 2 cathodes:<br>1st chrome<br>2nd titanium | 80 | 70 | 150 | 3 | 0.67 | 25 |




a)




b)

**Fig. 8.** The surface of a fragment of the knife made of steel 65G, a) with the TiN-Cr2N coating of 4 microns thick, and b) after heat treatment and polishing without the coating.

Behind the coating there is a transition zone, which differs in that it is relatively well etched with nital and has the thickness of 4–5 microns.

At the same time, as a result of the micro X-ray analysis, it is found that the prevailing part of titanium is located in the coating itself. Only a certain part of it is located in the transition zone

The method of the qualitative X-ray analysis, which was carried out using the setup URS 50, made it possible to trace the distribution of chemical elements in the TiN-$Cr_2N$ coating, the transition zone and the matrix, as well as to reveal inclusions of various kinds. In this case, the essence of the method was as follows: when interacting with atoms located on the surface of the sample (plate), the electron beam generated X-rays. At the same time, measurement of the wavelength and intensity of radiation made it possible to determine the presence of certain elements. In turn, the radiation intensity was characterized by the number of pulses that occurred over a certain period of time of the sample movement. Simultaneously, the profiles of the concentration distribution during the sequential movement of the plate were recorded.

The results of measurements while the samples were moved for a given distance using a microprobe were printed on a special device. The dependence of the radiation intensity on the coordinates of the points location was recorded on the diaphragm paper that made it possible to further determine the concentration of elements with an error of up to 2 %.

Scanning the electron beam on the plate surface allowed obtaining the parameters of the surface layer. However, the images that were received due to reflection in the electrons give a qualitative characteristic of the chemical composition of the coating, but such information stipulates determination of the relationship between the concentration of the coating and the microstructure of the surface layer.

It should be noted that on the X-ray photogram one can distinguish the lines that are characterized by the following phases: TiN, α-Ti, α-Fe. Determining the presence of $Cr_2N$ is quite a subjective process. This is due to the fact that the lines of such a connection usually coincide with the lines of other connections. In our case, chromium was not detected, but this does not prove its complete absence. This fact is explained by insufficient sensibility of this method for chromium detection.

## 4. CONCLUSION

A 4 micron coating of the system TiN-$Cr_2N$ increases the wear resistance of the tested samples (tribo units) due to the presence of titanium nitride. The coating is a smooth film, evenly distributed on the surface of the samples. It has strong adhesion with the base metal and is able to resist wear well.

The results of the laboratory tests make it possible to predict an increase in tribo unit wear resistance under the real operating conditions (especially with limited lubrication or without it at all).

## Abbreviations

EMM – earth-moving machine
IPC - ion-plasma coating
CIB - cathode ion bombardment
EP – excavating part
HFC - high frequency current

## REFERENCES


[1] G.A. Pilyushina, *Features of wearing working attachment of construction and road machine,* New materials and technologies in mechanical engineering, Bryansk: BGITA, 2009. (in Russian)

[2] V.I. Moshhenok, V.P. Tarabanova, N.A. Lalazarova, N.A. Proskurnya, *Selection of the material and the method for improving wear resistance of the bulldozer cutting elements*, Vestnik XNADU, no. 38, pp. 122–125, 2007. (in Russian)

[3] E.S. Vencel, A.V. Shhukin, *Improving wear resistance of the earth-moving machine excavating parts,* Kharkov, 2015. (in Russian)

[4] T.A. Roik, D.B. Glushkova, Yu.V. Ryzhkov, *Improving wear and corrosion resistance of parts of the pump-controlled hydraulic drive by applying ion-plasma coatings*, Kharkov, 2012. (in Russian)

[5] T.A. Roik, D.B. Glushkova, *Improving durability of molds for casting under the pressure of copper alloys,* Kharkov, 2013. (in Russian)

[6] V.S. Muxin, R.M. Kireev, S.R. Shextman, *Technology of applying vacuum ion-plasma nanostructured coatings Ti-TiN,* Mechanical engineering technology, no. 4, pp. 212-214, 2011. (in Russian)

[7] S.S. Dyachenko, I.V. Ponomarenko, *Ion-plasma treatment as a factor of increasing design hardness of steel products,* New materials and technologies in the metallurgical and mechanical engineering, no. 1, pp. 71–77, 2009. (in Ukrainian)

[8] E.S. Vencel, O.V. Orel, O.V. Shhukin, *Increasing the quality of lubricants, fuels and machine tribo units*, Kharkov, 2017.

[9] V.Yu. Gladkov, S.V. Karcev, I.N. Kravchenko, N.V. Afonin, *The modern technology of air-plasma spraying of wear-resistant coatings*, Construction and road machines, no. 5, pp. 30-34, 2003. (in Russian)

[10] E.S. Vencel, S.G. Zhalkin, N.I. Danko, *Improving the quality and increasing the service life of petroleum oils,* Kharkov, 2003. (in Russian)

[11] Yu.D. Grigorev, *Methods of the experiment optimal planning,* St. Petersburg, 2015. (in Russian)

[12] T.V. Meledina, M.M. Danina, *Methods of planning and processing of research results*, St. Petersburg, 2015. (in Russian)