Development of anti-adhesive coatings based on nitrides and oxides of zr by deposition from vacuum-arc plasma

E L Vardanyan, K N Ramazanov, A N Abramov, A Yu Nazarov and R Sh Nagimov
Ufa State Aviation Technical University

E-mail: vardanyaned@gmail.com

Abstract. Anti-adhesive coatings based on Zr nitrides and oxides deposited from the vacuum-arc plasma were developed. Laboratory tests that determine tribotechnical properties were conducted. Proved, that coatings based on nitrides and carbides increase the anti-adhesive properties.

1. Introduction

During the exploitation of machine parts in the sliding contact zone, a complex of physical, physico-mechanical, electrochemical, acoustical and other appearances, which affect the friction and metal wearings [1]. The most effective method of modification the surface properties of the tool is the deposition of functional coatings. Currently, the processes of physical deposition of coatings (PVD processes) on various products, including die tools, are becoming often used because of high reliability, versatility, the possibility of obtaining coatings of virtually any architecture, composition, structure with ensuring environmental cleanliness of processes in the production of tools.

Article [2] studies of the mechanism of interaction of aluminum alloys and tool material (with and without coatings) are given. According to the results of the research, established that the mechanism of aluminum adhering at hard coatings occurs in two phases: primary adhering due to micro unevenness of the coating; secondary transfer of aluminum on the surface. Coatings of CrN and CrAlN showed similar mechanism of interaction. The resistance to aluminum adherence of CrN coatings is lower than of CrAlN. Aluminum particles adhere to the surface of the coating and thereby are formed large dimensions, which leads to an increasing of the friction coefficient, metal wear and adhering on the surface of the coatings. To increase the resistance to adhering, it is necessary to improve the quality of the contactable surface (roughness).

Article illustrated the wear resistance and frictional characteristics of various hardening coatings at sliding friction without a lubricant. As a samples were used disks with a diameter of 50 mm and height of 35 mm, made of an aluminum alloy D16T (roughness Ra = 0,11 – 0,14 μm) with different hardening coatings: TiN, a carbon diamond-like film (CDLF), an anode and chemical oxidation. As a result of the researches established, that the formation of hardening vacuum-plasma coatings provides a significant, more than 10 times, increase in wear resistance of products in frictionless sliding without lubricant.

In the work dedicated to improve the resistance against the setting of aluminum alloys, as a protective coatings are considered coatings based on nitrides and zirconium oxides (ZrN and ZrO₂), because Zr has the least tendency to interact with an aluminum melt [5].
Article [4] contains results of researches and comparative analysis of various hardening coatings of resistance to adhering and scuffing at interaction with different working materials. Coatings were deposited to high-alloyed tool steel for cold working.

Regardless of the surface hardening technology used (nitriding or coating), the adherence of the material from the aluminum alloy to the surface of tool steel occurred at the beginning of the tests. Coatings of TiB$_2$ and TiC showed an increase in the friction coefficient of more than 0.5 immediately after the start of the tests. DLC coatings also showed fast increase of friction at a load of about 300 N, while TiN and VN coatings showed a more moderate increase in the friction coefficient. For all the surfaces studied, the increase in friction corresponded to the formation of a thick layer of the transferred aluminum alloy.

The results of the literature review showed that in order to increase the resistance to aluminum adherence, it is necessary that the roughness of the contactable surface is minimal; Solid coatings based on nitrides and oxides of Zr, CrAlN can be used as anti-adhesive coatings (aluminum alloys that are resistant to adherence). Because the friction coefficient of these coatings when interacting with aluminum alloys is minimal.

Thus, studies aimed at developing anti-adhesion coatings by deposition from a vacuum-arc plasma are actual.

2. Material and methods
Deposition of the coatings will be carried out at the upgraded plant NNV-6,6-I1, intended for condensation of the substance from the metallic plasma and surface modification by the non-self-sustaining high-current diffusion, arc and glow discharges, which is equipped with a gas supply system, a plasma generator with a filament cathode – “PINK”, evaporators. The technological modes of applying coatings at the installation of NNV-6,6-I1 varied within the following limits: pressure in the chamber P = 10$^{-1}$–10$^{-2}$ Pa; arc current I = 40 – 120 A; processing time 60-75 minutes; The temperature of the processed samples did not exceed 520°C. Scheme of the experiment (Fig. 1).

For the structure analysis of the instrumental material and the transition zone of the coatings-substrate will be used modern metallographic analysis techniques (Zeiss Axiotech 25HD Optical Microscope) and scanning electron microscopy (SEM JEOL JSM-6490LV).

To assess the effectiveness of the new method for modifying the surface of the instrument will be used laboratory stands, in addition to the generally accepted methods for determining the tribotechnical properties of surface modified layers, will be realized typical processes of cold working of metals by pressure.

ZrO and ZrN coatings were applied to the samples in the form of a ring with dimensions 380x280x20 from the tool material (Fig. 2), to study the antiadhesive properties when contacting with aluminum alloys.

The following types of coatings were applied to the samples: Zr-ZrN; Zr-ZrO.

![Figure 1. Scheme of the experiment:](image-url)
During the experiments, the samples were tested in the initial state without coating, with ZrN and ZrO coatings. A sample of the tool material is mounted on a laboratory bench, specimens of a cylindrical shape of aluminum alloys are placed in the holder, a load of 10 kg is fed to the holder through a load lever. The ring-shaped sample starts to rotate by contacting at the top with the aluminum alloy. During the rotate on surface there are formed scuffs and aluminum is adhered to the surface of the tool. When the friction force increases and the tool is subjected to a critical load, the motor automatically stops. The laboratory stand is shown in (Fig. 3.).

3. Results and discussion
Tool samples after the test are presented in (Fig. 4.). As seen, the width of the track on the surface of the rings formed as a result of contact with aluminum samples is different. In the course of the experiments, it was found that the stopping time of the motor for the original uncoated instrument sample was 1.5 seconds, for the sample with ZrO coating the value was slightly more than 2.3 seconds, and for the sample with ZrN coating - 7.2 seconds.
The tracks of the clad aluminum on the surface of the tool samples are shown in (Fig. 5.)

The results of measuring the maximum track width showed that the original uncoated sample and the ZrO coating are approximately the same and are 4.98 and 4.90 mm, respectively and 2.5 mm on the ZrN coating.

4. Conclusions
Thus, the results of the literature review showed that to increase the resistance to aluminum adherence, it is necessary that the roughness of the surface to be contacted is minimal; Solid coatings based on nitrides and oxides of Zr, CrAlN can be used as anti-adhesive coatings (resistant to adherence of aluminum alloys). The carried out researches have shown that the deposition of zirconium nitride based coatings improves the antiadhesive properties of the tool by 3 times compared to the uncoated tool material.

Acknowledgments
The work was carried out in the framework of project No. 17-48-020688 with the support of the Russian Foundation for Basic Research and the Academy of Sciences of the Republic of Bashkortostan.

References
[1] J A Mrochek [et al.]. *Technoprint*, 2004. - 369 p.
[2] Ivashchenko S A, Koida S G. “Vestnik BNTU”, No. 6, 2008 30-34
[3] M. Berger, S. Hogmark / *Wear* 252 (2002) 557–565
[4] B. Podgornik et al. / *Wear* 261 (2006) 15–21
[5] Graschenkov D V: *VIAM* / 2010-205320, viam.ru/public/