Research and development of anti-adhesive coatings deposited by vacuum-arc discharge plasma

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Abstract. In works devoted to the view of resistance against adhesion, as protective coatings of a coating based on zirconium (ZrN), since Zr has the least tendency to interact with an aluminum melt. A new technique for the quantitative determination of the adhesion of anti-adhesion coatings has been developed. On the basis of experimental data, it was found that among the selected types of coatings, the best result, from the point of view of enhancing the properties against adhesion, was a coating of zirconium nitride.

1. Introduction

Important factors of tool failure at the processing aluminum alloys can be adherence, the adhesion of the alloy to the working surface, followed by detachment, together with a part of the base metal, when the casting is removed. Adhesion of the first kind (cold scuffing) [1] occurs with sliding friction at low speeds, relative utilization and specific loads exceeding the current limit on contact areas in the absence of lubrication. Adhesion of the second kind [1] (hot scuffing) is observed during sliding friction with high velocities and loads, which leads to an increase in the temperature in the contact zone and the correspondence of the plasticity of the contacting materials.

To improve the resistance of molds against setting different technological measures are used: heat-resistant steels and alloys, bulk hardening and chemical-thermal processing (nitriding, cyanidation), microarc oxidation [2], as well as application of composite coatings are used.

The most suitable directional modification of the surface properties of the die tool is the application of functional coatings. At present, the processes of physical deposition of coatings (FOP or PVD processes) on various products, including stamping, obtaining all the advantages due to high reliability, versatility, the possibility of obtaining coatings of virtually any architecture, composition, structure, ensuring environmental purity of processes production tool [3]. Therefore, in this work, composite coatings were obtained from the deposition of vacuum arc discharge plasma.

In works devoted to the view of resistance against adhesion [4], as protective coatings of a coating based on zirconium (ZrN), since Zr has the least tendency to interact with an aluminum melt [5]. At the same time, multi-layer composite coatings based on intermetallic compounds of the Ti-Al system are considered as promising coatings for increasing resistance against setting, as this material has the following properties: retain their structure and strength at high operating conditions, sim is good in anticorrosion and antifriction properties.
Thus, the purpose of this work is the development of anti-adhesive coatings and their research on the adherence of the deformable aluminum alloys.

2. Methods of experiment

The samples were made from 4Х5МФС tool steel, the most common material for making molds for punching aluminum alloys. The diameter of the samples was 30 mm and the height was 7 mm. The deposition of composite coatings on the samples was carried out at the NNV-6,6-I1.

The following types of coatings were applied to the samples:
- Zr-ZrN;
- Ti-Ti3Al-TiAlN.

A special technique is developed based on the ability of the plastic material to spread over the surface when applying a vertical load to estimate the value of adhesion (figure 1). The ingot of the deformable alloy AK12D with a diameter of 8 mm and a height of 10 mm is installed on the coated sample. As the compression on the end surfaces of the sample, frictional forces will arise (the magnitude of the forces will depend on the friction coefficient and the adhesion of the coating) radial-directed to its center and preventing deformation in the horizontal directions. Arising forces are shown in figure 2.

![Figure 1](image1.png)

**Figure 1.** Scheme of the experiment 1 – cathodes, 2 – vacuum chamber, 3 – Worktable, 4 – Sample.

![Figure 2](image2.png)

**Figure 2.** Sample test circuit: a) Coefficient of friction and adhesion = 0; b) The coefficient of friction and adhesion is maximal.
Thus, for measuring the adhesion, the diameter (area) of the surface occupied by the imprint of the deformed sample can be used.

Testing of samples with composite coatings on adhesion of aluminum alloys was carried out on the Instron 8862 – system for testing the long-term strength and creep. The coated samples are installed in the furnace, the plate from the deformable aluminum alloy is mounted on top of the sample (figure 4). After installation, the oven is turned on and the samples are heated to 420°C. After the specimen is heated, the load is applied to the sample compression by 75%, while the aluminum alloy is pressed against the surface of the coated sample. After holding under pressure for 5 minutes, the load is removed and the samples are cooled in the atmosphere. After cooling, the aluminum alloy is removed from the surface of the samples and the coating is examined for the presence of areas with traces of setting. To quantify the setting of the coating properties, the ratio of the areas of adhesion of the aluminum alloy to the entire contact area is calculated.

The thickness of the coating was determined from the measurement of the well parameters. The well is obtained with the CSM Calotest. The roughness was measured with the Abris-PM7 profilograph.

3. Results
Photographs of the treated surface after measuring the thickness are presented on figure 3.

![Figure 3](image_url)

Figure 3. Image of the wells after measuring the thickness of the coating: 1) TiAlN; 2) ZrN.

The results of measurements of the coating thicknesses, as well as the roughness values of the samples prior to and after coatings are given in table 1.

| № | Coating | Thickness, μm | Roughness Ra, μm |
|---|---------|---------------|------------------|
| 1 | Original samples | - | 0.3636 |
| 2 | Zr-ZrN | 3.8 | 0.8614 |
| 3 | Ti-TiAlN | 4 | 0.9115 |

The results of measurements of the roughness before and after deposition of the coating confirm the statements that the quality of the surface after deposition declines [7].

Photographs of the samples installed in the system for testing the adhesion of the deformable aluminum alloy, before and after tests are shown in figure 4.
The value of the load was increased until the alloy was deformed by 75%. Photos of the surfaces of the test samples after testing and deformable alloys are shown in figure 5. A schematic representation of the zones of adherence of the investigated samples on the surface of the deformable aluminium alloy are presented in figure 6.

Figure 4. Installed samples in the Instron 8862 test system: a) before the tests; b) after the tests.

Figure 5. Images of samples (initial, with coatings) and deformable alloy after testing for adherence. 1) ZrN; 2) TiAlN; 3) Initial.

Figure 6. A schematic representation of the zones of adherence of the investigated samples on the surface of the deformable aluminium alloy: 1) ZrN; 2) TiAlN; 3) Without coating.
The tests of uncoated samples and ZrN, TiAlN coatings showed different results of adhesion of the deformable aluminum alloy to the surface of the samples. Investigation of the surfaces of the deformable alloy after testing with various coatings showed that in a sample without a coating, adhesion of the deformable alloy occurs practically over the entire contact area. The best result was shown by samples coated with Zr-ZrN, the adherence of the alloy occurred only along the perimeter of the contact area, which by volume is 26% of the total area of the contact section. In a Ti-Al intermetallic coated sample, the surface area on which traces of adhesion remained are 44.6% of the total contact area of the aluminum alloy. And for the original sample, the surface area on which traces of sticking remained are 60.2% of the total contact area. Thus, on the basis of experimental data, it was found that among the selected types of coatings, the best result, from the point of view of antiadhesion properties, was a coating of zirconium nitride.

Thus, according to the results of roughness measurements, it is established that when machining with a Zr-ZrN-coated die tool, a higher-quality product surface is obtained.

4. Conclusion
On the basis of experimental data, it was found that among the selected types of coatings, the best result, from the point of view of enhancing the properties against adhesion, was a coating of zirconium nitride. The results of model tests of punches with a coating of zirconium nitride showed an increase in resistance against the adhesion of the tooling with a coating against and an increase in the quality of the surface treated with a tooling with a coating. Additional processing of the samples after the deposition of coatings, to reduce the roughness, can also have a positive effect on the anti-adhesion properties of the coating.

Acknowledgments
The study was supported by the grant from the Russian Science Foundation (#15-19-10030).

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