Protective antifriction multilayer nanostructured coating by ion-plasma sputtering

A Urbahs, M Urbaha, K Savkovs and D Andrejeva
Institute of Aeronautics, Faculty of Mechanical Engineering, Transport and Aeronautics, Riga Technical University, Lomonosova 1A, k-1, Riga, LV–1019, Latvia
E-mail: Darja.Andrejeva_1@rtu.lv

Abstract. Unacceptable wear is the main problem of machines and mechanisms failure in most cases. One of the numerous solutions – specially designed protective antifriction coating – is introduced as a result of the research made. Protective coatings are the most prospective solution for problems of wear and friction. In comparison with various lubricants, protective coatings are more reliable and durable due to their better adhesiveness.

1. Introduction
There is sufficiently great variety of methods for the application of the protective antifriction coatings [1]. More often surface of an element is treated by the particles (ions, atoms, cluster) and the high-energy quantum flow. The ion sputtering is one of the fast-developing methods of the coating application and is considered as an appropriate method to solve wear and friction problem [2, 3]. When a solid surface is bombardeed by the positive ions and the particles are deposited on the element [4, 5]. Ion-plasma treatment in vacuum makes it possible to combine different layers in one technological cycle.

2. Experimental equipment and technique
The protective antifriction multilayer nanostructured coating was deposited in the modernised vacuum installation NNV-6,6-II [6, 7], which is designed for relatively small details treatment (not more than 200 mm in diameter and not longer than 250 mm). The protective antifriction multilayer coating was deposited on the samples of steel surface.

During the experimental studies, pure metals titanium, Ti and copper, Cu plasma sources were used – titanium, Ti as the electric arc vaporizer and copper, Cu as the magnetron. Ti has wide application due to its low density, high-tensile and heat-resistant but with several disadvantages as low modulus of elasticity, low enough wear- and corrosion-resistant, low running-in (in Ti-Ti pairs) and antifriction properties [8, 9]. These disadvantages may be solved by introducing an alloy of protective coating with such kind of metal like Cu. Copper has good corrosion resistant and scoring properties and easily is burning-in due to the its softness. The protective screen was mounted in front of the arc to minimise the droplet phase vaporizer Figure 1 [4, 5, 10].
The high-voltage source is used as a source of energy in the partly vacuum atmosphere where a process of coating deposition occurs. The inert gas ions are injected when the required level of vacuum is reached. The inert gas particles are ionised by the high energy discharge and are moved and fastened thus bombing the cathode and knocking-out or sputtering particles of the material deposited [3, 4, 11, 12]. Principles of operation of the vacuum installation NNV-6,6-I1 are condensation and bombing.

Ar and N are injected to deposit metals and their alloys on the surface of the experimental sample [13]. Vaporising Ti in the Ar media liquid metal atoms in the form of droplets are deposited on the steel surface of samples. The chemical reaction of plasma passes the formation of the TiN resulting while N ionizing. The second electric arc vaporizer and the injection of the N are stopped and intermetallic of TiCu is deposited after the deposition of the TiN [10].

To control the thickness of the coating the delay time of each installation work cycle is introduced [5].

The microstructure of coatings obtained were performed and analysed with the HITACHI S-3000N Scanning Electron Microscope and the BRUKER Quantax microanalyzer at 15kV and 16kV with wavelength 0,16 nm.

Roughness test was carried out with the TR100 Surface Roughness Tester help.

3. Coating obtained
To evaluate friction characteristics of the TiCu coatings obtained one of the task were to cover wider spectre of the Ti-Cu equilibrium diagram by varying the pressure and the current strength parameters in the vacuum chamber during the deposition and the location of the samples to plasma sources. The alloys of the top layer of the coatings present from Ti–51%Cu to Ti–93%Cu (weight percent) see Figures 2, 3 and 4.
Microstructure of coatings obtained were performed and analysed with *HITACHI* S-3000N Scanning Electron Microscope and *BRUKER Quantax* microanalyzer at 15kV and 16kV with wavelength 0.16 nm.

**Figure 2.** Ti-Cu weight percentage.

**Figure 3.** X-ray diffractograms for the *Ti-51%Cu* 138_3 sample.
Figure 4. X-ray diffractograms for the Ti-51%Cu 141_front sample.

Chemical composition of the 138, 141 samples varies: Cu – 50-60%, Ti – 40-50%, 139 samples Cu – 75-80%, Ti – 20-15% as shown by the colour of the samples – from silver to reddish gold – see Figures 5, 6 and 7.

Figure 5. 138 experiment obtained coatings.
All the samples obtained were evaluated by several criteria – colour, thickness of coating, microstructure, surface roughness, microhardness etc. There was conducted the Vickers hardness test [14] by a square based diamond pyramid indenter with load 20g, 50g, 100g and 150g. The microhardness of the coating obtained varies on chemical composition average HV$_{50}$$\text{141} = 145.7$, HV$_{50}$$\text{139} = 240.3$ and HV$_{50}$$\text{138} = 557.2$.

Roughness test was carried out with the TR100 Surface Roughness Tester help. The roughness was as following: for steel surface without coating – 0.51 Ra, but coated samples were up to 1.08 Ra.

The microstructure of coatings obtained were performed and analysed with HITACHI S-3000N Scanning Electron Microscope and BRUKER Quantax microanalyzer at 15kV and 16kV with wavelength 0.16 nm.

On the steel surface of the experimental sample layers of the TiN and intermetallic of the TiCu were deposited. The top layer of TiCu due to its softness filled micropores and roughness of TiN coating see Figures 8, 9 and 10. In this case the composite structure of the nitride is preserved.
Figure 8. 138_3 sample microstructure (×8000).

Figure 9. 141_1front sample microstructure (×8000).
4. Conclusions
The protective antifriction coating was made in the modernised vacuum installation by the method of ion-plasma sputtering. The multilayer antifriction coating of the titanium ($Ti$) and copper ($Cu$) composition in argon ($Ar$) and argon and nitrogen ($Ar, N$) media was deposited on steel surface. The thickness of the obtained protective antifriction multilayer coating is about $h \approx 2$-$5 \mu m$.

On the surface of the experimental elements was formed wear resistant titanium nitride ($TiN$) coating with the microhardness up to $HV=747$ and thickness obtained is about $h \approx 1$-$1.6 \mu m$. Titanium copper ($TiCu$) has a good burning-in and adhesion properties with microhardness up to $HV=550$ – due to the softness of the copper the time and quality of grinding is better, thickness is about $h \approx 1$-$3.4 \mu m$. Study on mechanical properties showed that average microhardness and roughness of the experimentally samples had increased 2-3 times in comparison with uncoated samples.

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