TRIBOTECHNICAL PROPERTIES OF COATINGS ON TITANIUM ALLOYS

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We compare the antifriction properties of different types of coatings on titanium alloys under conditions of boundary friction as applied to parts of the hydraulic cylinders of an aircraft. We show that gas-thermal titanium carbide coatings clad with nickel and with both copper and nickel have better antifriction characteristics than ones obtained by chrome electroplating, nickel chemoplating, thermo-oxidation, anodization, etc.

Titanium alloys are known to have low antifriction properties and to interact very actively with air at temperatures above 500°C, which causes seizing and losses in serviceability of parts in real friction assemblies. In this case, the coefficients of dry friction of titanium on titanium and other metals are as high as 0.48–0.68.

The low wear resistance of titanium can be explained by features of its hexagonal close-packed crystalline lattice, which assures twinning along several planes at once in the case of sliding friction. This causes accumulation of vacancy-type defects and pronounced activation of surface layers, i.e., an increase in internal energy [1]. A decrease in the accumulated energy (passivation) reveals itself in seizing. In this case, one observes interdiffusion of atoms from contacting metals according to the vacancy mechanism. As a result, common lattices are formed at the sites of contact.

Greases slightly improve the antifriction properties of titanium alloys. Surface layers interacting with grease and gaseous media are modified due to saturation with oxygen, nitrogen, hydrogen, and other elements. An increase in the carbon content in the surface layer of a titanium alloy [2] results from decomposition of molecules of grease that penetrates into microcracks of the friction surface. This process causes an adsorptive decrease in strength that initiates and intensifies a dispersion process associated with an increase in the density of blocked dislocations to values exceeding the critical one. Intense destruction of tribo-elements of a titanium alloy in a grease medium is also connected with penetration of other elements into surface layers [3].

For hardening of surfaces of titanium and its alloys, one uses various coatings that can be divided into three groups:

- diffusion coatings obtained by saturation of the surface layer with various elements, e.g., oxygen, nitrogen, boron, carbon, silicon, etc.;

- electroplating coatings, chemical coatings, and coatings obtained by deposition from vapors, melts, etc.;

- gas-thermal coatings and coatings obtained by various methods of vacuum physical deposition, e.g., the ion-plasma method, the magnetron method, electron-beam spraying, etc.

To the last group, we assign coatings obtained by hard-facing, which have found no application in practice due to oxidation of the substrate material, formation of brittle intermetallides, and low purity of the hard-faced surface.

The most extensively used and promising methods of hardening titanium alloys in the aircraft industry are: chrome electroplating, thermo-oxidation, nickel chemoplating, and anodization [4]. However, for various reasons (insufficient homogeneity and stability of the obtained properties of the coatings, a limited range of physico-mechanical characteristics, and high labor input of the processes), they do not fit the requirements imposed upon friction assemblies made of titanium alloys. Recently, we have observed the growing use of spraying methods such as
as vacuum physical deposition (ion-plasma spraying) and gas-thermal deposition (plasma and detonation spraying). A disadvantage of gas-thermal coatings is their rather low adhesive strength, whose increase requires additional technological operations [5].

An assessment of the serviceability of titanium alloys subjected to surface hardening by various methods presents some difficulties connected with the lack of a single procedure for determination of antifriction properties of materials. Therefore, coatings should be tested under conditions that are closest to the actual ones. Analysis of the antifriction properties of various coatings as applied to individual parts of aircraft with limited service life is of obvious practical interest.

The combination “axle box – rod of a shock strut” works under conditions of boundary friction in reciprocating motion. It has been established that chrome-plated rods made of 30KhGSA steel are predominantly rejected due to abrasive wear, loss of airtightness of the assembly, and sometimes seizing.

In hydraulic cylinders that are not subjected to high internal pressure the surfaces are built up by hard chromizing, nickel chemoplating, and anodization. Hard chromizing of parts of hydraulic cylinders that experience high stresses encounters difficulties. Unequal values of the thermal expansion of the coating and the base metal, low toughness of the coating, and significant stresses favor cracking, flaking, and chipping of individual portions of the coating. A fine network of macrocracks (which cover up to 30% of the surface) accelerates corrosion of the base metal, and residual tensile stresses in the coating increase the sensitivity to corrosion. Electrodeposition of chrome coatings on titanium alloys is associated with additional difficulties due to increased oxidizability of the alloys, their tendency to hydrogenation, and sensitivity to stress concentrators.

We compared the antifriction properties of coatings on VT-22 alloy as applied to parts of a hydraulic unit of an aircraft that were obtained by various methods of surface hardening (see Table 1). The coatings were applied to the face surfaces of ring-shaped specimens of dimensions 30 x 40 x 10 mm, were machined to a roughness $R_a = 0.32 \mu$m, and were tested in friction on BrAZhMts 10–3–1.5 bronze and electrolytic chromium in AMG-10 hydraulic fluid at a sliding rate of 0.05 m/sec and pressures of 2.0 to 14 MPa. We determined the friction coefficient and the wear rate. For plasma and detonation spraying, we used a titanium carbide powder clad at most 60% with nickel and copper. Microscopic examinations were performed on a Superprobe-733 microanalyzer using optical and scanning electron microscopy.

Preliminary tests of VT-22, VT-1, and VT-3-1 titanium alloys under conditions of boundary friction in AMG-10 hydraulic fluid on copper, aluminum, and titanium alloys and steels and of various types of coatings showed that, even under light loads, evidence of seizing, intense wear, deterioration of surface purity, and a high and unstable friction coefficient are observed. Thus, in friction assemblies of aircraft, one can use titanium alloys only with protective coatings that exhibit the required tribotechnical characteristics. In view of the tendency of titanium alloys toward hydrogenation and their sensitivity to stress concentrators and overheating, it is pertinent to focus our attention on coatings obtained by various methods of spraying that possess none of these disadvantages and have a wide range of properties. We note that their tribotechnical characteristics have not yet been adequately investigated.

We established that practically all the coatings under investigation improve the tribotechnical properties of VT-22 alloy and decrease the friction coefficient by a factor of 1.5–2.0. However, the methods of hardening differ greatly in efficiency (Fig. 1).

Metallographic examination of the friction surfaces and the products of wear and measurements of the friction coefficient showed that conditions of boundary friction in the system of (BrAZhMts 10–3–1.5)–(VT-22)–(chrome electrodeposit) are met up to a load of 14 MPa (the sliding rate is 0.05–0.25 m/sec). Beyond this range, the antifriction properties deteriorate substantially due to wear of the bronze, the particles of wear increase in size, and signs of surface destruction are observed. The friction coefficient becomes unstable, i.e., mechanochemical similarity is disrupted.

The range of serviceability of nickel chemoplating is much narrower. At loads above 2 MPa the pair wears out intensely, at 6 MPa the coating abrades without completing the 1000 m of control, and the bronze seizes with the regions of the titanium alloy from which the coating flaked off.

Thermooxidation is effective at a load of up to 4 MPa, and then the wear rate and the friction coefficient increase (Figs. 2, 3). When the pressure is increased, the oxidized surface is destroyed in a brittle manner due to flaking of local microregions.