FUNCTIONAL COATINGS APPLICATION FOR STRENGTHENING AND RESTORATION OF AVIATION PRODUCTS

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Abstract. The article deals with the analysis of modern technologies of surface hardening and restoration of the working parts of aviation products. The technologically sophisticated methods of obtaining multifunctional composite coatings with an application of effective sources of energy are described. These methods permit structures with predetermined physical and mechanical properties to be formed on working surfaces. The results of testing alloys and coatings under conditions of abrasive and erosive wear are tested. Practical recommendations on application of the aircraft parts surface strengthening and restoration techniques, taking into account conditions of operation, are brought forward.

Keywords: surface strengthening, restoration, coating, structure, wear, wear resistance.

Introduction

The successful solution of production efficiency and the transition from a state-run economy to intensive development are closely connected with more rapid scientific and technical progress. For this purpose, it is necessary to create and implement fundamentally new types of technology and engineering connected with material science. This especially concerns parts subject to friction, upon which the safety and durability of modern machinery, particularly aircraft, depend. The problem of serviceability of aviation products (AP) is urgent in every country. This is especially true in the countries of the CIS, in connection with their aging aircraft fleets and also with limited means necessary for the restoration of worn out parts.

Parts subject to friction work under conditions of fatigue, abrasion, erosion, gas and hydro-abrasive wear, cavitations, fretting-corrosion, etc. For example, turbine blades are exposed to high temperature gas flow and significant load during operation and are worn due to the propagation of erosive wear on their working surfaces.

In operation, not only can the wear of the airfoil portion of a blade be observed, but also the wear of the clearance between the rotor blade tip shroud and alternating tension in blades, resulting in the break-down and failure of a blade.

Components of landing gear are exposed to abrasive wear. Gas-abrasive wear can be observed on helicopter rotor blades operated on unpaved landing airfields and in dusty areas. Gas-abrasive wear is observed most distinctively on the parts of the gas-air duct of the gas-turbine engines of helicopters. When a helicopter operates on the ground or hovers at a low altitude, dust and sand can easily be lifted into the air by the airflow caused by the rotating rotor and this dust cloud is kept suspended. As a result, air mixed with abrasive particles enters the intake system of engines, promoting intensive development of gas-abrasive wear.

Mineral and artificial oils, greases, working liquids, and solid lubricants are used to lubricate most parts of planes and engines exposed to friction.

Foreign particles such as dust and sand enter these lubricants, promoting the development of wear processes and sometimes cause contacting surfaces to jam. From 85 to 90 percent of planes are removed from operation because of amortization of components, while expenditure of metal for spare parts manufacturing exceeds 20% of annual melting [1].

The problem of increasing the heat and corrosion resistance of AM parts, as well as increasing their fatigue strength, fretting stability, etc., is extremely pressing. All these factors urgently require the development of technological methods promoting the serviceability of parts subject to friction.

Increasing the resistance of parts to wear with the help of technological methods can be done in two directions:

1. Manufacturing parts using wear resistant alloys and composite materials.
2. Forming on the working surfaces of the parts functional coatings, the structure of which provides high tribological properties.

At present, some brands of alloyed steel are used as wear-resistant steel. However, the usage of these steels leads to a rise of the cost of the products. Beside, alloyed steels do not always provide the necessary tribotechnical characteristics of the parts that work under certain conditions of contact interaction. In a number of cases, it is impossible to satisfy a complex of operational requirements by application of traditional structural materials. More prospective is the creation of functional coatings having predetermined physical and chemical properties. Application of such coatings not only provides high serviceability for parts subject to friction, but also allows a lot of rare alloyed materials to be saved, because in most cases the thickness of the coating applied on the surface of the parts ranges from 5-8 up to 250-300 microns.

The purpose of the present work is monitoring the technological methods of surface strengthening and restoration of worn out AP parts and determining of tribotechnical characteristics of coating by means of new technological methods.

Methods of research

A set of complex methods have been applied in research; they allow to be conducted a complete analysis of worn-out parts subject to restoration and model samples before and after the tribotechnical tests.

The condition of working surfaces was studied with the help of metallographic and electron-microscopic analyses. The microstructures of surface layers were examined with MMP-2P and Neophot-32 optical microscopes. Electron-microscopic research was carried out with a “CamScan-4 DV” scanning electronic microscope. The chemical structure of surface layers was determined with a help of the “Link-860”. Phase structure was studied with an X-ray diffractometer. Processing the results of the experiments was carried out by means of mathematical statistical methods.

The tests under conditions of gas-abrasive wear were carried out on installation and by means of a technique explained in [2]. At 3000 or 6000 rpm of the rotor, the speed of the abrasive flow of 38 or 76 m/s is provided. The size of the abrasive particles varied from 300 up to 900 microns. The tests were carried out at 15, 30, 60, and 90 degrees of angle of attack. The required angle of attack was provided by the inclination of the working surface of the sample relative to the horizontal plane. Samples 20x15x4 mm in size were ground up to a roughness of the working surface Ra=0.16-0.32 microns. Quartz sand with 0.5-0.9 mm grain size and relative moisture content of not more than 0.15% were used as abrasive material.

The wear resistance of the alloys and coatings under study with abrasive, which was not rigidly fixed, was carried out according to the aforementioned method and on the installation [3].

Hardened steel and nickel based surface in materials were used in experiments.

Results of research

At present the operations to provide quality and surface strength of parts subject to friction are carried out in two-ways:

1) Surface treatment, with a change of the structure of the working layer without any change of the chemical composition;

2) Application of functional coatings.

Among the methods of surface treatment, there are surface plastic deformation (SPD), mechanothermal, surface thermal, electromagnetic, magnetoimpulsive, electromechanical, laser, and electron-radial processing. Each of these methods of treatment has advantages and shortcomings and should be used in view of conditions of the operation and of the material of the part to be hardened. For example, SPD, which is one of the most widespread methods of surface hardening, increases surface strength hardness, and wear resistance.

After SPD, parts become less sensitive to fatigue failure; scratches and micro cracks that remained on a surface after the previous technological operation disappear. Thus the limit of elasticity, fluidity, and endurance grows.

The method of shot blasting was widely used among the varieties of methods of SPD treatment. This method results in the formation of cold hardening in the surface layer, increasing hardness and wear resistance. The application of these methods of hardening allows the durability of components such as turbine blades, rods, springs, spring plates, stamps, etc. to be considerably increased.

Traditional methods of surface thermal treatment are carried out by heating parts with a gas flame, by high-frequency current (HFC), or by laser. The HFC method of surface hardening has the widest application in machine building, auto tractor, and electro technical engineering. Parts such as gears, shafts, axes, cams, and fingers for clutches working under conditions of friction and wear and subjected to dynamic loads are treated by this method.

As a rule, these parts have high surface hardness and wear resistance, and their core remains viscous, which provides components with high fatigue durability. The thickness of the hardened layer, which amounts to 1-10 mm, is adjusted by the frequency of the electric current. For removal of residual pressure after hardening, the details are exposed to low tempering.

More essential results are achieved by thermo-mechanical (TMT) and electromechanical (EMT) treatment, at which the durability of carbonaceous alloys considerably increases and their plasticity is barely reduced. The given methods are based on the joint effect of plastic deformation and temperature changing over time according to certain laws.

The varieties of TMT are high temperature TMT and low temperature TMT. Application of these methods increases the degree of deformation up to 12%. It causes wear resistance to increase more than 1.5 times and wear resistance under conditions of abrasive wear process to increase 1.5-2 times.

The essence of EMT is that, under the influence of the tool to which the current is supplied, a partial melting and swelling-up on the edges of the working edge of the tool occurs. This method is applicable for restoration of parts with deterioration less than 0.35 mm. Process flow diagrams of EMT are subdivided in two kinds: electromechanical smoothing (EMS) and electromechanical swelling-up (EML). The choice of technological diagram of EMT is determined by the purpose of the part and by its operating conditions. At present, research of such methods of surface processing and restoration of the worn out surfaces of the parts as electrohydroimpulsive, electromagnetic, and magnetoimpulsive are carried out.

These methods have not found wide application in industry because systematized data of wear resistance of hardened surfaces and systematized data about the optimum technological mode of processing component members have not been accumulated.

Laser treatment of parts is one of the most prospective methods of surface machining. High speed of heating and cooling, high temperatures, minimum time for full high temper of metal, high values of specific energy – all these makes it possible to obtain necessary mechanical and physical properties at the surface layers. Laser treatment increases wear resistance, fatigue strength as well as endurance of machine parts and mechanisms.

Laser treatment is used to strengthen crankshafts gear wheels, compression rings, distributing shafts, and pistons.

Electron-ray technology [ERT] for material treatment, which is being developed at the E. O. Paton Institute of Electrical Welding of the National Academy of Sciences of Ukraine, belongs to the most effective science-based high technologies and has wide prospects [4].

The methods of galvanic and electro-chemical coating as well as nickel plating, chrome plating, phosphate coating, cadmium plating, copper plating, bronze plating, etc. are the traditional methods used to restore of worn-out parts in aviation engineering. Such methods are used at aircraft repair plants for restoration of more than 50 worn-out parts. The coatings are used for parts, landing gears, rods of hydro cylinders, bolts, etc. Galvanic silver is an antifriction coating. And therefore, to protect the component members from setting – one of the disastrous kinds of wearing – galvanic silver is to be applied on compressor blades.

Composite electrolytic coverings [CEC], having the second phase in their structure that sufficiently affects mechanical and physical properties and terminological properties in particular, are more prospective [5]. The distinctive feature of composite coatings is that either the coating itself is powder or a powder medium is used to form it.

The basic method to obtain composite electrolytic coatings [CEC] is to inject the powder particles into the galvanic setting. For each specific case, the composition and structure of the coatings depends on technological parameters of the process [6].

Composite electrolytic coatings may be obtained as a solid boron layer or solid carbide layer. They may also be obtained as eutectics in which solid inclusions of boride and carbide layers are found or in the form of eutectics in which solid inclusions of boride and carbide are evenly distributed in a plastic matrix.

The composite electrolytic coatings may be obtained, depending on the quantity and size of the particles in the matrix (nickel or iron in particular) and depending on the composition of electrolyte and parameters of the process of electrolysis. Composite electrolytic coatings also depend on duration and temperature of homogenizing.

Both coatings with hard inclusion and coating with solid lubricants, which greatly improve the tribospecifications of coatings, are obtained after heat treatment by means of simultaneous input of two or more components into the matrix during electrodeposition. The typical microstructure of composite electrolytic coverings on the basis of nickel is shown in Figure 1.

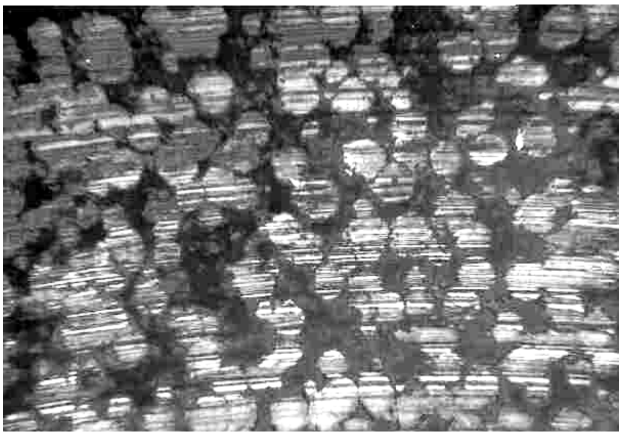


Fig 1. Microstructure of CEC Ni-B after tribotechnical tests

To introduce a method to restore aviation parts, there is no necessity to install special equipment because the standard equipment of galvanic shops in an aircraft plant can be used. The main advantage of CEC is that being a simple combination of two widely used methods of galvanic and thermal coating standard equipment for it application can be used.

Nowadays the methods of gas thermal spraying and vacuum deposit applying are some of the most actively developed directions in the field of protective coatings. Electric arc, gas flame, plasma, and detonation spraying are part of the group of industrially developed methods. They are united by one principle – forming coatings from different particles being heated and accelerated with the help of high temperature gas flow. The structure of coatings created by all these methods is laminated. It is made of more or less discrete particles with more or less distinctive boundaries of separation.

In practice, all four gas thermal methods are used in aircraft repair plants. The wide application of these methods of restoring worn AP parts is determined not only by physical and mechanical properties obtained by parts after spraining, but also by productivity of the process. Thus, the output is expressed in kg/hour for detonation spraining, in dozens of kg/hour for gas flame and plasma, and in hundreds of kgs per hour for electric arc metallization.

Gas flame coatings are applied to the parts of gas turbine engine to reduce the radial gap between the rotor and the stator of the turbine, increasing efficiency and decreasing fuel consumption. However, application of this method of gas thermal spraying is limited due to weak adhesion of the coating with the main surface, due to porosity, which ranges 5-25%, and the low coefficient of using energy during spraying (2-12%).

Plasma coatings provide higher physical and mechanical properties than gas flame ones. At aircraft repair plants these coatings are applied to the parts made of constructive steels and of nickel alloys, etc. Powders of self-fluxing alloys are used for spraying on the basis of nickel (Ni-Cr-B-Is-C).

When applying plasma coating, it is advisable to use standard equipment. Argon-nitrogen-hydrogen or propane-butane-air mixtures are recommended as power supply sources.

Imported equipment “Plasma technique AG” (Switzerland), “Metko” (USA-Italy), “Kactolin-Utektic” (Switzerland) is widely used for plasma coatings.

Among the shortcomings of the aforementioned equipment are its high cost and the necessity to use expensive and highly purified rare gases.

Micro plasma spraying of coatings, which is realized with the help of MPP plants, is a variety of plasma technologies. This technology is used to restore turbine blades, details of locking armature, stamping units, press molds, etc. More powerful micro plasma devices are prospective, including inverter and module.

In spite of all the advantages, plasma spraying has the following distinctive shortcomings: insufficient strength of cohesion of coatings and bases, high porosity, small output of plasma jet energy use for heating powder, high noise and radiation level, and relatively expensive equipment.

One can partially avoid these shortcomings by using detonation spraying. The porosity of such coatings obtained on simpler equipment amounts to 0.5-1.0% and the strength of cohesion of coatings and bases reaches 160 MPa. The microstructure of detonation coating is shown in Figure 2.

It is worthwhile to note that detonation coating is recommended for the restoration of parts that have small working surfaces and do not require large amounts of coating material. This method is used for the restoration of gas-turbine engine components.

Compared to gas-detonation, plasma-detonation is more prospective. The equipment used for this method permits additional electric power to be introduced into the combustion products and provides control of plasma-power density from 10^3 to 10^7 W/cm^3 and temperature control from $2{\cdot}10^3$ to 10^4 K. The equipment for plasma-detonation spraying permits to obtain high quality functional coverings to be obtained. The productivity of the process achieves 10 kg/h of powder at power of 10 kW.

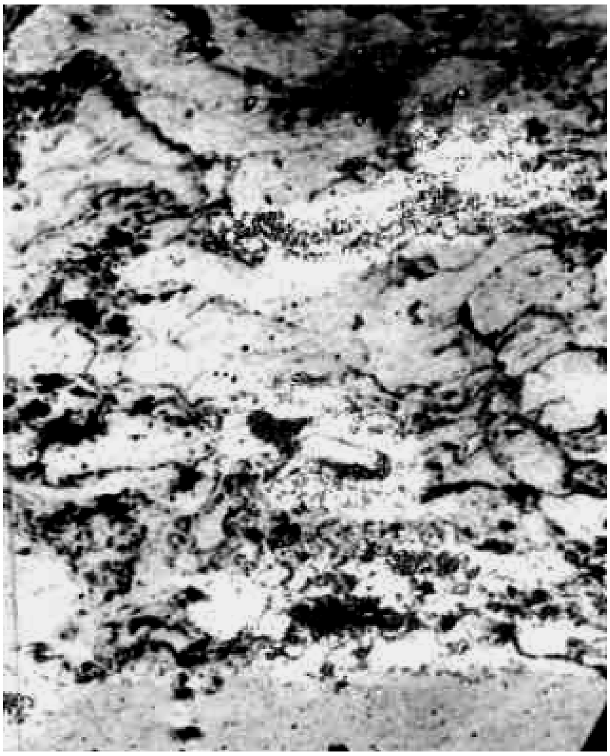


Fig 2. Microstructure of composite detonation coating, x400

The electric-spark (ESA) method has great possibilities and is used for strengthening material and durability of machines. This method is used to increase heat- and corrosion-resistance of surfaces; to increase the durability of metal-cutting, woodworking, and fitter work tools, etc; to make roughness for the following galvanic coating; to facilitate soldering of hard solder able materials with usual solder (application of an intermediate layer, e.g. copper); to increase the size of machine parts during their repair, and to change the surface properties of articles made of nonferrous metals and tool steels.

The essence of this process is alloying the surface layer of a metal part that is a cathode with the material of an electrode (anode) by spark discharge in the air. As a result of the chemical reaction between the alloying element and the dissociated atomic nitrogen and air carbon and the interaction with the material of the part, the hardening structures and compound chemical combinations (e.g. high-dispersion nitrites, carbonates and carbides) are formed in surface layers. As a result, an extremely hard and durable diffusive coating is formed. The final form of the coating obtained by the ESA method is given in Figure 3. Besides craters, ridges, and cavities one can see pores on the processed surface, and on the bottom of some craters one can see fused spherical particles.

With the ESA method, complex physical and chemical processes take place. First, the anode material is transferred to the cathode. As a result, the structure and the phase in the cathode surface are changed. Second, the cathode material is repeatedly affected in a number of ways.

This method is noteworthy in connection with the possibility of creating multifunctional coatings of gradient and discrete structure having a wide range of physical and chemical properties. This fact is confirmed by the results of experimental tests of coatings under abrasive wear conditions (Figure 4)

Fig 3. Electronic photo of the coating before experiment

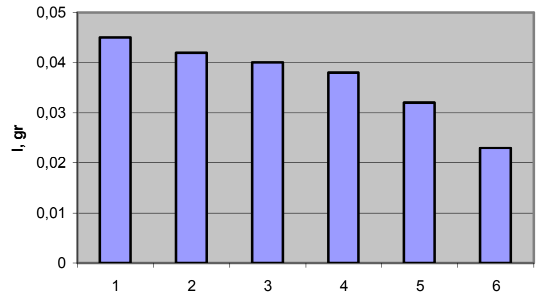


Fig 4. The steel and coatings wear under abrasive conditions ($Si0_2$): 1 – steel 30; 2 – PI8; 3 – graphite; 4 – 30ХГСА; 5 – ВК8; 6 – ВК8+graphite

While repairing AP, the ESA method is used for strengthening such parts as cams, guides, locks, clamps, pushers, wedges, and perforations of base members.

The possibilities of chemical and thermal treatment (CTT) of metals and alloys are unlimited. Composite diffusion coatings obtained by the CTT method are particularly prospective. The data of the authors testify to the fact that this matter is prospective for scientific research as well as for practical use [7]. If we consider that the periodic table contains 80 elements that are not rare, the general number of systems that have phases with valuable properties amounts to a number with 27 digits.

Numerous methods of CTT can be applied not only for surface hardening, but also for restoration of worn-out parts like high precision elements (plungers, sleeves, and fuel pump needles and nozzles), the serviceability of which can be effected by contaminating impurities. According to statistics, the inorganic amount of contaminating impurities contained in fuel of the engine fuel system is about 70%.

The most dangerous are solid particles, the size of which exceeds the gap of plunger pair. Ingress of abrasive particles on the functional surface of high-precision element causes wear and results in breakdown of fuel supply; fuel consumption increases, starting and power properties of an engine become worse, and overheating can also occur. Using CTT to harden and restore plunger pair parts sufficiently increases their serviceability.

Experience of operation and repair of AP shows that blades and discs are the most heavily loaded parts of an engine. While in operation, they are exposed to alternating and centrifugal loads, to extra loads caused by high-frequency vibration, and high temperatures. Their intensive wear is caused by high-temperature oxidizing processes of the working surfaces of the parts, which stimulates the formation of oxide films and their further destruction under the effect of abrasive gas flow. Materials operate at a breaking point of their capacity due to stress, temperature, and environmental factors. Affected by gas flow, abrasive particles plough the oxidized surface of the parts. They form deep scratches, tear outs, and cavities. Traces of partial melting can also be observed (fig. 5a). Cracks and burnouts may appear on the sectors of inlet vanes (fig. 5 b) and twirlers. Such parts are rejected.

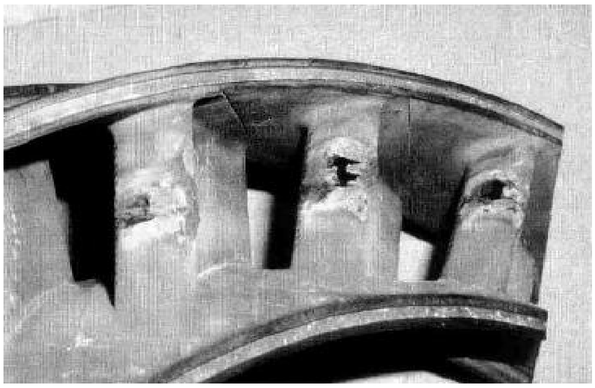
Atmospheric gas (air, oxygen, carbon dioxide, nitrogen) research and their role in gas-abrasive wear were carried out for constructive steels and nickel based material. The research was performed within the particles speed range of 38-78 m/sec, and the size of the particles was 0.5 mm. Some results of this research are given in Fig. 6.

The analysis of this data proves that gas ab resave wear processes proceed more intensively in oxidizing atmospheres than in inert atmospheres. Maximum wear resistance characterizes the surfacing material recommended for restoration of the worn rotor blades ЭП-367.

Recently, the range of parts hardened by laser alloying has increased. When restoring worn parts with laser surfacing, the dimensions of the parts subject to repair are

a

reduced by an amount equal to the thickness of the working layer of the coating with subsequent application of the coating, taking into consideration machining allowance in accordance with the operational sheets and process charts of laser processing. This method is used to restore the parts of the D-36 engine.



b

Fig 5. Blade after 8000 hours operating time (a) and inlet vanes sectors after 12000 hours operating time (b)

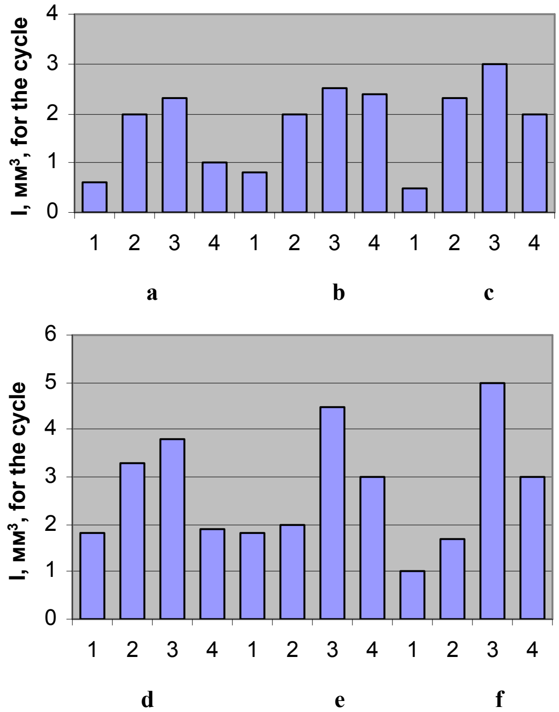


Fig 6. Diagrams of volume wear of the materials under study in different atmospheric gases (1–nitrogen; 2–air, 3–oxygen, 4–carbon dioxide by V=38 m/s, A=0,5 mm) a-ЭП-367; b-ЭИ-893; c-ЖС6К; d-И-625; e-steel Х18Н10Т; f-steel 45 hardened

The sphere of application of complex methods of surface hardening increases. Research directed to hardening parts with self-spreading high-temperature synthesis, ion implantation, electronic and ray radiation methods are being carried out.

Conclusion

Progressive methods of applying coatings will improve the quality, reliability, and durability of aviation products. They will also increase the period of time between repairs and decrease expenses for spare parts, which will result in saving materials and labor.

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