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THE INFLUENCE OF AEROSOL GAS-DYNAMIC SUSPENSION CLEANING ON SURFACE OF THE AIRCRAFT PARTS

The specificity of the surface microgeometry formation under the influence of aerosol gas-dynamic suspension flow was considered. The composition and character of metallic surface layer formation of aircraft parts was investigated. The possibility of surface material composition and properties adjustment changing aerosol gas-dynamic suspension flow parameters was determined. The hypothesis about the possibility of using aerosol gas-dynamic suspension flow to form corrosion-resistant coating on the detail metallic surfaces was set up.

Розглянуто специфіку формування мікрогеометрії поверхні під дією аерозольного газодинамічного суспензійного потоку. Досліджено склад та характер формування поверхневого шару металевих поверхонь елементів авіаційної техніки. Встановлено можливість регулювання складу та характеристик поверхні матеріалу зміною параметрів аерозольного газодинамічного суспензійного потоку. Висунуто гіпотезу про можливість використання аерозольного газодинамічного суспензійного потоку для нанесення антикорозійного покриття на металеві поверхні деталей.

Introduction

Nowadays industry of aircraft maintenance and repair requires the application of more efficient and environmentally sound technological processes. The processes of detail surface cleaning are of great importance as time spent on cleaning makes up one third of total repair time.

Using aerosol gas-dynamic suspension (AGDS) method, which is described in work [1], is one of the directions in efficient and pollution-free cleaning processes. But the issues of impact action and intrusion of abrasive particles in the details surface are not enough covered.

It was determined in works [2; 3], that processes which are based on the effect of solid particles impact on treated surface, proceed in different ways: the impact is done by an abrasive particle; the impact is done by an aerosol gas-dynamic flow which contains solid particles; suspended abrasive particles impact on a treated surface in the special emulsion which is sprayed with compressed air.

The impact of abrasive particles cuttings edges on a treated surface is short and has impulsive character. Thus the process of deformation of solid starts with elastic deformation which is followed by plastic deformation and destruction of solid. At the same time it is indicated, that high speeds of deformation (≈100 m/s) can cause destruction of solids without plastic deformation, consequently, fragile destruction. When the stream of abrasive particles bombards metallic surface, the following changes take place in the surface layer: elastic deformations, plastic deformations, deformations of shift and chip.

Formation of microrelief

Thus, the formation of microrelief under the influence of aerosol gas-dynamic suspension flow can be presented as follows [2]: the initial stage consists of destruction of the most prominent microroughnesses, plastic deformation of their bases and elastic deformation of practically all of the treated surface; the next stage of treatment begins after deleting the most high asperities on the surface, located at the distance of no more than 0,8*d* (*d* is a middle size of abrasive particle) one from another, and consists of surface roughness mass averaging by plastic deformation of microasperities and microcavities of practically all of microrelief.

Experiments showed that at collision of polydisperse particles and detail individual aerosol particles remove different volume of mass from the detail surface. Particles which have abrasive constituents with sharp sides cut into the metal and take off a scale; some particles, which have depth of cutting less than radius of cutting edge round-up, scrape the surface without shavings. Other aerosol particles, running into the treated surface, squeeze out the metal into sides, as it is shown in the work [2], the maximal depth of particle intrusion into a metal $h_{\max}$ is expressed by equation:

$$h_{\max} = a\left[\frac{5\pi\rho_r(1-\mu^2)V^2\sin^2\alpha}{4E}\right]^{\frac{2}{5}}, \qquad (1)$$

where

a, ρ_r are the radius and density of particle material;
μ is Poisson index of the treated material;
V is particles speed at the moment of collision with the surface;

α is angle between the axis of flow and treated surface;

E is the module of elasticity of the treated material.

It follows from the equation (1), that the more particle size and density and aerosol flow speed are the more intensive the process of mass taking off is.

When liquid is constituent in the flow the abrasive particles must overcome resistance of liquid film before the destruction of surface layer.

The resistance force at penetration through the liquid film is caused by the components of strain ductile tensor. The value of resistance force with high precision coincides with the level of resistance to penetration of thin wedge in the ideal liquid [4]. If we ignore the gradient of pressure in cavity microrelief, then resistance to penetration of abrasive particles F can be defined from equation:

$$F = \pi\rho V^2 H\left(\frac{\pi}{2\alpha} - 1\right)^2, \tag{2}$$

where ρ is density of suspension (determined by special method [2], in our case ρ is equal to water density);

H is depth of penetration final value, here $0<\alpha<\pi/2$.

It is necessary to note, that in this task:

$$H = R_{\max}, \tag{3}$$

where $R_{\max}$ is the largest height of surface microrelief profile, which is impacted by the flow.

The speed of abrasive particle is determined from the equation [4], taking into account the force resistant (2) to penetration of particles into cavity of microrelief and equation (3):

$$V_{\max} = \frac{V}{\left(1 - R_{\max}^3 \frac{\pi\rho(\pi-\alpha)^4}{m}\left[\frac{2}{3}\ln 2(\pi-\alpha) + \frac{1}{3}\right]\right)^{\frac{\ln 2(\pi-\alpha)}{\frac{2}{3}\ln 2(\pi-\alpha)+\frac{1}{3}}}}$$

where m is mass of abrasive particle.

While determining destruction depths under the influence of green silicon carbide with the grain of 40 – 60 μm with speeds of more than 140 m/s, deviation between the calculated and experimental data is within the limits of 20%. It is caused by the increase of interaction speed, which leads to decrease of destroyed surface elastic deformations and increase of cavitation damage of the abrasive particle water shell and its intensive fragile destruction.

For the clay particles with speed of 300–400 m/s the calculated depth of intrusion is 0,5–1,5 μm.

The surface quality influences wear resistance of movable joints, strength of fixed joint fits, corrosion resistance, light- and heat-reflecting ability of the surface.

Microgeometry of surface which is treated with the aerosol gas-dynamic suspension method is the surface without directed tracks of treatment, with shallow, evenly distributed surface cavities and asperities without microcracks. Mat type of surface after the treatment is explained by the absence of extended surface layers of metal oriented in one direction which is the result of concentrated action of abrasive particles.

Relatively deep cavities and marks on rough surfaces are not fully removed at AGDS treatment and remain with changed, fuzzy edges.

The increase of the details fatigue-resistance, for example, after the treatment with hydro-abrasive method, is explained by the fact that little, evenly distributed cavities, which were formed as a result of impact-cutting action of abrasive particles, are not sharp concentrators of stress. Fatigue-resistance of steels is increased within the limits of 15 %, at the same time wear resistance is increased by 25–30 %. The microgeometry of surface also essentially influences corrosion resistance, it is related to formation of stable passivating films [2].

The surface of samples before and after the AGDS method treatment was investigated with Auger-spectroscopy on the modernized electronic spectrometer 0940C-10-005 of G.V. Kurdumov Metal-physics Institute in the National academy of sciences of Ukraine [5]. The electronic Auger-spectroscopy (EAS) method is based on the processes of ionization of internal atomic levels with primary electronic beam, Auger-transition without emission and output of Auger-electron to the vacuum, where it is registered by an electronic$_{\max}$ spectrometer. Auger-electrons give small peaks on an energy distribution diagram.

Let's consider the process which flows as a result of ionization of the isolated atom with electron impact. When falling electron with large energy beats the electrons out of internal level, a vacancy which appeared at the same time is filled with another electron, for example, transition of $L_1 \rightarrow K$. Energy $E_K - E_L$ during such transition can be released in the form of typical x-ray emission or passed to other electron, for example, which is on level L_2. This electron goes out vacuum and is registered as Auger-electron.

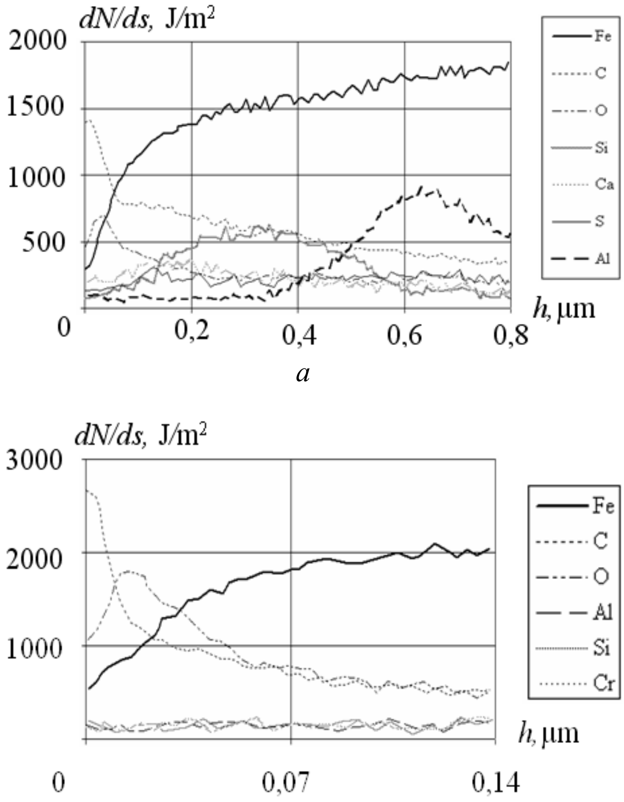
The energy of Auger-electrons is characteristics of target material and does not depend on energy of falling beam. Two energy levels and three electrons are necessary for the Auger-process. That is why in the atoms of hydrogen and helium Auger-electrons can not appear.

It is possible to conduct not only quality but also quantitative analysis of the surface chemical composition by EAS. The methods of chemical analysis by EAS are divided into two groups: calculation and empiric. The first group is based on the use of levels which link the current of Auger-electrons with the concentration of the proper element and various physical factors; introduction of the Auger-peaks relative amplitude factor; use of different parts relative sections ionization. The methods, based on comparison of Auger-peaks amplitude of investigated element and external standard or internal reference element and on the construction of graduated curves, belong to the second group.

The layer analysis is conducted by etching samples surface with the beam of argon ions of 1,5 mm in diameter with energy of 3000 eV and density of current 400 mkA/cm^2. EAS allows to identify parts by the energy of Auger-electrons if these parts have atomic number of $Z>2$ and to conduct layer analysis simultaneously for eight components with depth discreteness more than 0,5–1 nm. In EAS information is related to the surface area with thickness of 2–4 atomic layers. The absolute sensitivity of method is approximately 10–14 g, relative sensitivity for volume admixtures is of the order of 10^{-3} at. %.

The disk-shaped samples with the diameter of 10 mm and thickness 5 mm, whose surface was preliminary turned into the 14th class of roughness, were used for the Auger-spectroscopy method analysis. Two identical samples (from one stick) were made of the steel 30ХГСА and titanic alloy ВТ3. One of the samples from every pair was treated according to AGDS method with the parameters of installation: pressure on the entry of the nozzle is 0,6 MPa; concentration of abrasive particles is 1:3 by mass according to clay and water; distance to the treated surface is 0,07 m; axis slope angle of flow to the plane of surface is 90°; time of treatment is 60 s. After the treatment samples are washed with the clean distilled water and dried in the flow of warm-compressed air.

The untreated pair of samples was used as reference to define stabilization level of concentration of main parts included in composition of alloys. The spraying of surface layer of the treated samples was carried out before the main parts concentration came out to the stable (according to the reference) level. Research results are presented on fig. 1.



b

Fig. 1. Changes of specific energy efficiency of 30ХГСА material parts by the layer thickness:
a – before the AGDS method treatment;
b – after the AGDS method treatment

Analyzing dependences of the energy emission intensity change for different parts of the steel 30ХГСА by the depth on fig. 1, it is possible to make conclusion, that for the first 30 minutes of spraying (depth to 0,1 µm) the layer of organic matters, settled on the sample surface from the air, is taken off. Then between 0,1 to 0,5 µm there is the layer of steel 30ХГСА, enriched with silicon to 20 at. %. Small admixtures of Ca up to 2,7 at. % are explained by remains of abrasive particles on the material surface, which could be removed by washing with high-speed flow of water. From the depth of 0,4 µm to approximately 1 µm the layer of steel is enriched with aluminum up to 40 at.% (possibly with the oxide of aluminum). The transition phase, decrease of silicon content and increase of aluminum content, is on the depth of 0,5 µm. Consequently, porous two-layer coating, which is schematically presented on fig. 2, appeared on the surface of steel 30ХГСА.

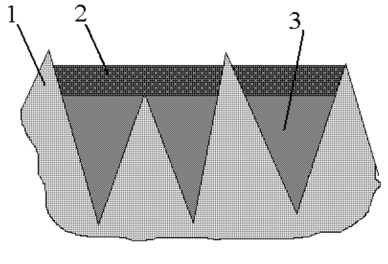


Fig. 2. The scheme of two-layer coating after the AGDS method treatment:
1 is backing material;
2 is layer enriched with silicon;
3 is layer enriched with aluminum

From fig. 1, *b* based on the theory of mathematical statistics [6] it is possible to define the middle depths of silicon and aluminum particles bedding.

The function of the investigated random quantities is named the statistical estimation of unknown parameter of theoretical distribution. General mean is an arithmetic mean of the general aggregate parameter values. The parameter of certain element atoms amount distribution on the limited, identical for all of values surface area, is considered to be the depth of spherical particle centers bedding *h*:

$$\overline{h} = \frac{\sum_{i=1}^{N} h_i m_i}{\sum_{i=1}^{N} m_i}, \qquad (4)$$

where $\overline{h}$ is middle depth of bedding, μm;

h_i is value of material atoms bedding depth, that is digitized by the graphic digitizer Windig25 based on the dependence on fig. 1, *b*;

m_i is value of specific intensity of atoms energy;

N is amount of digitized points on graph.

General dispersion is determined for the description of general aggregate bedding depth values dispersion around the mean value. The general dispersion *D* is an arithmetic mean of the general aggregate atoms bedding depth values square deviation from their mean value. *D* is determined from the equation:

$$D = \frac{\sum_{i=1}^{N} (h_i - \overline{h})^2 m_i}{\sum_{i=1}^{N} m_i}. \qquad (5)$$

Standard deviation $\sigma = \sqrt{D}$.

Let's limit the sampling of h = 0,35–0,8 μm for the aluminum general mean bedding depth determination, and to the sampling of h = 0–0,6 μm for the silicon general mean bedding depth determination.

Calculation results of general aggregate parameters of the aluminium and silicon bedding depths in accordance with (4), (5) are presented in table.

Descriptions of the corrosion resistant coating layers distribution

Material	Mean bedding depth *h*, μm	Dispersion *D*, μm	Standard deviation *σ*, μm
Aluminum	0,6352	0,0221	0,1486
Silicon	0,3191	0,0255	0,1596

Conclusion

The layer of aluminum has more dense structure, than the layer of silicon, because it has greater hardness and gets deeper into the material of backing, leaving free cavities which are occupied with silicon particles.

It is known that changing the composition of oxide layers, it is possible to regulate the corrosive behavior of steel in different conditions [7]. The previous investigation of corrosion resistance of the metallic surfaces treated according to AGDS method are presented in work [8].

Thus, changing the parameters of AGDS flow it is possible to form or avoid formation of the corrosion resistant material layer on the metallic surfaces of parts.

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