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VACUUM METAL WEB COATING WITH CERMETS

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ABSTRACT. The deposition of cermet coatings on metal webs - thin sheets and foils - is intended for improving their corrosion and abrasive resistances or imparting definite functional properties to them. Due to a small substrate thickness and its ability to deform freely the coating deposited considerably affects mechanical properties of the material. In contrast to metal coatings the cermet ones deposited in vacuum are brittle and contain internal stresses of markedly higher concentrations. This leads to deformations of web-substrate or to microcracking of coatings.

One of the ways to improve the cermet coating resistance is an enhancement of its plasticity through the application of alternative metal and cermet multilayered structures. Another way is an intentional formation of local inhomogeneities in a layer deposited that can act as sinks of internal stresses. When coating by the vacuum electric-arc method these inhomogeneities may be in the form of macroparticles-products of the erosion of a cathode used for electric arc discharges.

The results obtained formed a basis for developing a technology for the production of web with Ti-TiN-TiC-coating deposited for protective and decorative purposes. Such a coating imparts golden coloration of a required shade to the web and reveals higher corrosion and abrasive resistances which allows to apply the material as a replacement for gold foil when finishing external and internal pieces of an architectural appearance.

I. INTRODUCTION

The vacuum coating of metal bands and foils is used for solving a great many problems, for example:

- an improvement of the corrosion resistance of web surfaces [1];
- the production of ultrathin copper web [2];
- the production of bi- and three-metals [3], and others.

At the same time, one of most traditional technologies dated from very old times and based on the application of ultrathin web has not so far found a new development. We bear in mind ultrathin foils of gold and silver used for finishing details of architectural appearance and artistic articles.

In ancient times these materials were widely used for a decorative finishing of architectural details both inside (cornices, modelling) and outside (domes of cathedrals, sculptural ornamentation, etc.). They are being used at present on a limited scale, mainly, for renovating and solving separate artistic and architectural problems. Simultaneously, the potentials of the ultrathin finishing metal materials application that were noticed yet in old times are unlimited indeed as it helps to impart a decorative effect of metal-coating to surfaces of practically any dimension and shape. It should be noted that the duration of such a coating does not now exceed 10 to 15 years and is, mainly, defined by the weather and abrasive wear of gold webs.

A wider application of ultrathin metal web as a finishing material is hindered, above all, by two circumstances: first, such a web can be produced from highly plastic materials only of which some are very expensive (gold, silver), others do not have the resistance required and rapidly lose their decorative properties, particularly, in an atmosphere of an industrial town. The other circumstance consists in the fact that, for example, ultrathin gold and silver webs are being so far produced manually by thinning a sheet of metal through the impact action. In the USSR this fact makes the price of an article by 5 to 7 times higher than the cost of starting material. Finishing webs with a decorative metallized layer on polymer base produced at present by some firms do not have the required resistance which limits their applications to artistic articles and details of a decor.

Recent successes in the technology of vacuum protective-decorative cermet coating deposition based on the usage of refractory compounds open new horizons for the

technology of production of finishing materials on the bases of ultrathin metal webs. This work presents some results obtained in a study of the applicability of the vacuum-plasma technology of decorative metal web production.

2. EXPERIMENTAL TECHNIQUE

The experimental set-up for the realization of the vacuum electric-arc deposition of cermet coatings on webs is schematically shown in Fig.1 [4]. Samples of metal webs to be coated were fixed on a substrate-holder that could rotate around the axis of the working chamber. A RF-voltage was applied to the substrate-holder from a generator with operating frequency $f = 1.76\text{MHz}$ and a potential of self-polarization regulated within 50 to 1500 V. The surface temperature of web was measured in the process of coating using the IR-pyrometer. The supply of reactive gases to the working chamber was realized by using a 4-channel system of metered gas supply with maximal flow rates of 50 to 200 cm^3/min per channel. The concentration and the level of plasma activity were defined by Langmuir probes operating in a mode of ion saturation and by the emission analysis method. The thickness of coating was evaluated in the coating process by registering intensities of the ultrasoft characteristic X-ray radiation induced by irradiating the web being coated with a diagnostic electron beam.

The coating was accomplished using vacuum electric-arc sources of plasma fitted with an evaporating cathode. Two of such sources were placed within the working chamber, the working cathode end surface of one of them being in a range of direct visibility from substrate surfaces. This evaporator was used for coating by a direct deposition from the cathode gas-metal plasma jet. A second source was placed on a special electromagnetic plasma-guide-separator in such a way that the working cathode surface would be out of the range of direct visibility from substrate surfaces. During the source operation the vacuum-arc plasma deviated by an angle of 90° moving along the toroidal magnetic field lines of the plasma-guide in the direction of substrates and macroparticles - a droplet-phase product of the cathode erosion - were trapped at diaphragms disposed on the plasma-guide walls. As a result, at the output of the plasma-guide it was possible to produce a jet of atomic-pure gas-metal plasma with ion current up to 2 A and a uniform density distribution within a spot of more than 150 mm in diameter.

The deposition of cermet coating of Ti-TiC-TiN-system

on samples of aluminium, titanium, copper and steel webs 4 to 50µm thick was studied.

To evaluate the corrosion resistance of coated web samples, the rapid potentiodynamic test method was used allowing to derive anode polarization curves for dependences of the electric current density on the electrode potential (for material studied). These dependences reflect the nature and the intensity of corrosion the essence of which is behind anode processes. A three-electrode electrochemical cell with chlorine-silver electrode used for the comparison's sake was used with a corrosive fluid—a halogen-containing water solution [5]. Simultaneously, the chemical resistance of coated webs in 0.01 mol/l water solutions of nitric, hydrochloric and sulfuric acids as well as in alkali NaOH was studied by the gravimetric method.

The corrosion resistance of coatings was characterized in this case by the corrosion index defined by the equation:

$$K = \frac{1}{S} \frac{\Delta m}{\Delta t} \left[\frac{g}{m^2 \cdot \text{hour}} \right], \quad (I)$$

where Δm is the change of samples in weight during the corrosion test in Δt time, S is the surface area of samples. For testing various coating for effects on the corrosion resistance of web samples of web of equal surface area and coated on both surfaces were prepared. The kinetics of solution was studied at the solution temperature 25°C. Errors in weight measurements of web samples of 20 x 20mm² did not exceed 10⁻⁶ g. The microgeometry and mechanical properties of coatings were defined on compact blank samples that were processed in plasma simultaneously with web samples. The surface roughness of coatings was estimated using the profilograph "Talysurf-5M 120".

In addition, studies of the abrasive resistance of web through the evaluation of its pliability to polishing in suspensions with different concentrations of abrasive particles were carried out.

3. PHYSICAL PROCESSES IN THE DEPOSITION OF CERMET COATING FROM VACUUM-ARC PLASMA

Gas-metal vacuum-arc plasma is characterized by ionization and inhomogeneity of high degree. According to

the data in [6] obtained by the massenergy spectrometry the concentration of ions Ti in vacuum arc burning on titanium cathode is 27% for Ti^+ , 67% for Ti^{++} and 6% for Ti^{+++} at the directional motion energy of 65, 39 and 34 eV, respectively.

In accordance with our measurements carried out by the contactless optical method by measuring Doppler shifts in wavelengths of copper ions Cu^{++} radiation lines performed along and across the direction of the copper arc-plasma motion, their energy is 45 eV and reduces with an increase of the gas pressure and the strength of magnetic field.

Absolute concentrations of nitrogen atoms in Ti-N₂ arc were measured by the emission spectroscopy method which were $n_N \sim 10^{14} cm^{-3}$ at nitrogen pressure $p = 0,1 Pa$ and arc current 150 A [7].

The measurements have also indicated a rise in the concentration of ions and of excited atoms in low-pressure arc-plasma with a strengthening of magnetic field which is attributed to an increase in the mean free path of electrons and to the related enhancement of a frequency of collisions of atoms and electrons. Moreover, according to the data of probe temperature measurements the electron temperature rises from 1 or 2 to 5 eV with the strengthening of magnetic field from units to hundreds of Oersted.

Measurements performed using the cylindrical Langmuir probe have shown that the density of charged particles in vacuum arc placed into longitudinal magnetic field reduces as $n_e \sim L^{-1}$. A stronger dependence found for the density of the mass flow $\rho v_{th} \sim L^{-1,4}$ can be explained by the character of distributions of neutral and droplet phase flows [8] (a flow of macroparticles - droplet phase - propagate predominantly at small angles to the surface of electrode [6]).

Note that these dependences are qualitatively retained in the case when vacuum arc enters a curvilinear magnetic field of the plasma-guide-separator. In this case the jet length is measured along the maximal plasma density line.

When a plasma jet interacts with the web surface the latter heats up which can be evaluated from the energy equilibrium equation:

$$\rho_s c_s \delta_s \frac{dT_s}{dt} = \psi(t) \frac{j_i}{z_i e} [(\bar{E}_i - \bar{z}_i q_e \phi_s) + \bar{z}_i \lambda_2 \lambda_k] - (\epsilon_{s1} + \epsilon_{s2}) \epsilon T_s^4 - \beta(T_s - T_w) \quad (2)$$

where T_f is web temperature, T_w is temperature on chamber walls, ρ_f , C_f , δ_f are the density, the heat capacity and the thickness of web, respectively, φ_f is the potential of the web surface in plasma, j_i , E_i , \bar{z}_i are the ion flow density, the average energy of ions and the average charge of ions, e is the electron charge, $\lambda_{\bar{z}}$ is the average ion recombination energy, λ_K is the atom condensation energy, β is the heat emission coefficient defined by interactions of substrate with gas molecules, ϵ_{s1} , ϵ_{s2} are emissive capacities of front and back surfaces of web, and σ is the Stefan-Boltzmann constant.

In the case of vacuum of average level when the mean free path is $\ell_a \gg L_{sw}$ (where L_{sw} is the distance between substrate and cooled wall of the chamber):

$$\beta = p_g \sqrt{\frac{2R_0}{\pi M_g T_g}}, \quad (3)$$

where T_g , p_g are temperature and pressure of gas, M_g is the mass of gas molecule, R_0 is the gas constant.

The value $\psi(t)$ is the controlling parameter specifying the time of interaction between the ion flow and the web surface:

$$\psi(t) = \begin{cases} 1 & \text{- at the deposition of ions} \\ 0 & \text{- when the deposition of ions} \\ & \text{does not occur} \end{cases}$$

In the case of coating aluminium web with titanium it is possible to take: $\bar{z}_i \approx 1,8$; $E_i \approx 75 \text{ eV}$; $\lambda_{\bar{z}} \approx 7 \text{ eV}$; $\lambda_K \approx 170 \text{ cal/mol}$; $\epsilon_{s1} = 0,2$; $\epsilon_{s2} = 0,05$; $p_g = 5 \cdot 10^{-4} \text{ Pa}$ [9].

From the controlling parameter - the bias potential applied to the substrate-holder - and the ion flow density given in different ways it is possible to calculate thermal conditions of freely fixed web sample in the process of one-side coating using the equation (2).

Thus, at $\psi(t) \equiv 1$; $\varphi_f = -20 \text{ V}$; $j_i = 1,5 \text{ mA/cm}^2$ we found that the time of heating web of $10 \mu\text{m}$ in thickness to a temperature of 300°C was about 1 min.

4. MICROGEOMETRY AND MECHANICAL PROPERTIES OF CERMET COATINGS ON ALUMINIUM SUBSTRATE

To study the process of microgeometry formation on a surface when depositing cermet coatings from a vacuum electric-arc plasma jet samples of a base for hard magnetic disks were taken as substrates. The samples are aluminium disks the surface of which after turning is pro-

vided with NiP coating of up to 20 μm in thickness and then polished to a surface roughness of $R = 0.0008 \mu\text{m}$, $R_p = 0.04 \mu\text{m}$; some of the samples with poorer surface roughness parameters ($R_a = 0.015$ to $0.035 \mu\text{m}$, $R_p = 0.06$ to $0.1 \mu\text{m}$, $R_z = 0.055$ to $0.1 \mu\text{m}$) were taken immediately after turning and did not have NiP-sublayers. After coating the surfaces were measured for the reflection coefficient, for the coating thickness and for roughness parameters and the sample surface was microphotographed.

Fig.2 shows dependences of roughness parameters on the time of the TiN-coating deposition from a direct jet and from an atomic-pure jet of vacuum-arc plasma separated from macroparticles. The dependence of the coating thickness on the deposition time is also included here. It is seen that the coating from a separated arc plasma jet does not substantially affect the surface roughness up to the thickness of $\delta_c \approx 0,5 \mu\text{m}$. At the same time when coating from a direct jet the surface reveals unevennesses of units of micrometer already in the first minutes of the coating process.

The coating of aluminium surface with titanium nitride having hardness $H_H \approx 2000 \text{ kg/mm}^2$ and substantial internal stresses leads to fracturing of the coating along grain boundaries of aluminium. To alleviate the effect, a Ti-sublayer was introduced between the surface of the aluminium base and TiN-coating. Continuous network of cracks typical for TiN-coating without Ti-sublayer is substituted in this case by unconnected lengths of microcracks disposed sporadically and initiated probably by defects present on the original surface. A further lowering of the fracture probability can be ensured by a purposeful deposition of macroparticles on to the surface coated. Such particles play a role of sinks for internal stresses in the coating deposited provided it does not lead to a notable reduction of the reflection coefficient of the coating. This can be achieved by periodical switching of a direct deposition source on. In this way practically poreless $\text{TiN}_x\text{Cl}_{1-x}$ - coatings on aluminium substrate with the reflection coefficient 0.8 to 0.9 have been obtained. By changing ratios between concentrations of reactive nitrogen and acetylene gases it became possible to achieve different coating coloration: from golden and silver to black and - and to change the character of reflection from diffusional to mirror.

5. A STUDY OF THE CORROSION AND ABRASIVE RESISTANCE OF METAL WEBS WITH CERMET COATINGS

Two-layer cermet TiN-Ti-coatings were studied on sur-

faces of metal webs from steel, copper, titanium and aluminium. Fig.3 shows the dependence of a pitting-formation potential on nitrogen pressure in the process of coating 20 μm thick copper webs with TiN. Simultaneously, the values of characteristic X-ray radiation of nitrogen and copper induced by the irradiation of the TiN-coating surface by a diagnostic electron beam ($E_e = 2 \text{ keV}$) were compared. It is seen that with growing of gas pressure the intensity of the characteristic X-ray radiation of nitrogen reduces and that of copper increases which relates to the reduction of the deposition rate and the coating thickness due to the dispersion of titanium atoms on atoms and molecules of nitrogen. Simultaneously, with the reduction of the coating thickness the pitting-formation potential increases which characterizes a reduction of the corrosion resistance of the surface [5, 10].

Examples shown in Fig.4 illustrate the effect of TiN-coating on the corrosion resistance of different metals. As is seen in the anode curve for TiN deposited on a ceramic substrate the TiN-coating itself does not corrode in a chemically active medium studied.

Taking into consideration a higher plasticity of aluminium and the availability of ultrathin aluminium web ($\delta \leq 4 \mu\text{m}$) produced on a large scale the Al-web was used in further studies as a base material.

Studies of the corrosion resistance of aluminium webs with TiN- and Ti-coatings are carried out by the gravimetric method. samples with TiN-coatings differed both by the thickness and the nitrogen concentration distribution and by the deposition method: they were coated from a direct flow of Ti-N₂ vacuum-arc plasma (containing macroparticles) or from a separated flow of atomic-pure fully-ionized Ti-N₂ plasma.

Table I contains values of corrosion indices as functions of exposure time in 0.01 mol/l water solutions of NaOH, HCl, HNO₃, H₂SO₄ for samples with TiN-coatings deposited from an atomic-pure flow of Ti-N₂ plasma at various exposure times (2 and 4 min.), for samples with two-layer Ti-TiN-coatings, for those with Ti-TiN-coatings deposited directly from Ti-N₂ plasma (without separation of macroparticles), for samples with Ti-coatings and for samples of original Al-web without coatings. In all the cases the web thickness was 15 μm .

A comparison of results obtained indicates that the corrosion index of samples with TiN-coatings deposited from a separated jet of Ti-N₂ plasma distinguishes in-

significantly from that of original Al-web reducing with an increase of the coating thickness.

The character of variation of the corrosion index for Al-web with TiN-coating and for original Al-web is practically similar.

Simultaneously, the corrosion indices of Al-webs with Ti-coatings vary in dependence on the type of solution used in the same way as the corrosion indices for pure Ti [11] and the course of test cycle they change considerably slower than in the case of samples with TiN-coatings.

These results are attributed to a high brittleness of TiN-coatings deposited from an atomic-pure plasma jet. Such coatings reveal a high hardness, a fine-grained close-to-amorphous structure, large internal stresses and, as a result, do not practically have plasticity. Due to the fact local actions in regions of microcracks and other defects of a film when Al is subjected to etching lead to an intensive growth of microcracks and to scaling of coatings over a vast surface area. At that, in places of coating scaling the surface of Al-web without oxide film exposes which has a higher corrosion index than the original (oxidized) Al-web.

Fig. 5 where a photograph of a stretch of the Al-web surface with TiN-coating after etching in the H_2SO_4 solution is shown convincingly substantiate the supposition about the brittle nature of the TiN-film fracture. It can be also seen that the major interaction takes place at the interface film-Al-web surface (TiN-film itself does not interact with the solution).

This explanation was confirmed by further studies of the corrosion resistance of Al-web with Ti-TiN-coating.

Table I. Corrosion indices for aluminium web with cermet coatings

Reactant (0.1 mol/l solution T = 25°C	Corrosion index $K \text{ g/m}^2 \cdot \text{hour}$					
	Al	Al+Ti	Al+TiN* No. 1	Al+TiN* No. 2	Al+Ti+ TiN* No. 3	Al+Ti+ TiN* No. 4
I	2	3	4	5	6	7
NaOH	0.0091	0.0005	0.0071	0.003	0	0
HCl	0.0012	0.0004	0.0024	0.0021	0.00012	0.00010

I	2	3	4	5	6	7
HNO ₃	0.0011	0.0005	0.0023	0.0022	0	0
H ₂ SO ₄	0.0021	0.0015	0.0033	0.0031	0.00031	0.00020

Note: Sample No.1 - 0.3 μ m coating deposited from a separated jet of vacuum-arc plasma (2 min.),
 No.2 - same with = 0.6 μ m (4 min.)
 No.3 - coating from separated plasma
 No.4 - coated by direct deposition (without separation).

When a Ti-sublayer is used a better adhesion of TiN-coating is ensured and the continuity of the Ti-sublayer in microcracks of TiN-coating remains intact. The plasticity of Ti-sublayer ensures the protection of its continuity even at crumpling of the foil. Because of this the Ti-TiN-coating safely protects the surface of Al-web from an interaction with a chemically active medium.

At that time the corrosion index is defined by the corrosion resistance of coating material and does not correlate to the base.

It should be noted that, as follows from Table I, the corrosion resistance of coatings deposited from a direct flow (without separation) is somewhat higher than that deposited from atomic-pure plasma which, probably, relates to a high plasticity of the layer Ti-TiN containing a droplet phase due to a partial relief of internal stresses on sinks contained in the coating-macrodefects-Ti-particles of tenths to units of micron in size.

The abrasive resistance of Al-web samples with Ti-TiN-coating was studied by gluing them on a flat surface of a steel holder and by polishing using suspensions of diamond powders of different grain size to a complete removal of coating layer over one-third of the surface area of the sample. The results obtained were compared with the speed of polishing compact samples of Al with Ti-TiN-coating which was defined as a polishing time in which the height parameter of roughness reduced by a factor of 2. The results obtained (Fig.6) permit to affirm that the abrasive resistance of the aluminium web surface coated with Ti-TiN-film is not practically lower than that of the surface of compact samples of a aluminium with the same coating.

6. ANALYSIS OF POTENTIALS FOR APPLYING ALUMINIUM WEB WITH

PROTECTIVE-DECORATIVE CERMET COATING ON INDUSTRIAL SCALE

In the course of 1986-1990 we have gained a certain positive experience in the industrial application of Al-web with $\text{Ti-TiN}_x\text{Cr}_y$ - coatings of various shades of gold and silver. Such a web named "TOMDECOR" was used for finishing areas of roofs of orthodox churches and for finishing architectural details of the decor of modern concert halls. It was also used for decorative finishing of frames for paintings and of details of articles of jewellery. In the latter case an ultrathin annealed Al-web not more than 4 μm thick with $\text{Ti-TiN}_x\text{Cr}_y$ - coating of 0.5 to 0.7 μm in thickness was used whereas the thickness of a web used for finishing external parts of houses and buildings was 15 to 25 μm .

A study of the web surface with $\text{Ti-TiN}_x\text{Cr}_y$ - coatings after a three-year atmospheric action under conditions of an industrial town has shown practically full absence of abrasive-corrosive wear traces and of a loss of decorative properties. A long (in the course of 4 years) usage of articles with ultrathin (less than 4 μm) Al-web coated with $\text{Ti-TiN}_x\text{Cr}_y$ allowed to establish that the surface of articles coated with such a web does not lose its decorative properties as a result of frequent dusting which gives it an advantage over traditionally used ultrathin (under 1 μm) gold foil or its substitutes on a polymer base which do not reveal resistance to the abrasive wear. Al-web with $\text{Ti-TiN}_x\text{Cr}_y$ - coating was also tested for a long-time action of sea water. This test was performed by placing a web sample on the underwater part of a sea liner. A visual observation of the web surface after a half-year navigation showed full absence of corrosion traces and of any loss of its decorative properties. Besides, it was found that the foil surface did not have a growth on the remaining part of the bottom surface deteriorating the traveling performance of the liner.

Basing on an experience of the application of Al-web with protective-decorative coating the economic efficiency of the technology was estimated.

Some results of the economic efficiency indices calculation of the technology of production of Al-webs with protective-decorative cermet coating are given in Table 2. Main initial data on costs of materials used and on the equipment are taken from [12] and from our studies of marketing in this field of technology. In this connection the calculation performed is tentative and allows to estimate the efficiency of the technological process under laboratory conditions when coatings are being deposited on separate sheets of web (200 x 200 mm^2 in dimension). In

the case of charging web in rolls it is possible to expect a considerable increase in the productivity of the process and a reduction of the cost price of the product. Nevertheless, the technology "FOMDECOR" is rather effective even at its realization under lab conditions as its cost efficiency due to the application of the material "FOMDECOR" exceeds 700 000 USD a year at operating one lab installation in the context of average world prices for gold. Actually, the economic efficiency is notably higher as (as was mentioned above) the cost of finishing ultrathin web of gold is 5- to 7-fold higher than that of gold of the same weight.

Table 2. Main indices of the economic efficiency calculated for the technological process of production ultrathin metal foil with decorative coating.

Nos. :	Indices	: Units	: Cost in USD
I :	2	: 3	: 4
1.	Annual yield of product with coating	thou, m ²	3.8
2.	Annual wages	thou. dol.	155775
3.	Annual material consumption		
	- cathode	kg	380
	- gas	bottle	8
	- base (aluminium foil)	kg	19
	- electric power	k ^W /h	41540
4.	Average cost of materials		-
	- cathode	dol./kg	16
	- gas	dol./bottle	10
	- base	dol./kg	1.9
	- gold in bars	dol./g	13
	- electric power	dol./k ^W /h	0.2
5.	Price of the installation	dol.	500000
6.	Annual current expenses for coating	dol.	170243
7.	Cost of an annual production of aluminium web with Ti-TiN _x Cl-x - coating	dol.	206343
8.	Cost of an equal amount of ultrathin gold web (1 μm), the price being 13 dol./g	dol.	938600

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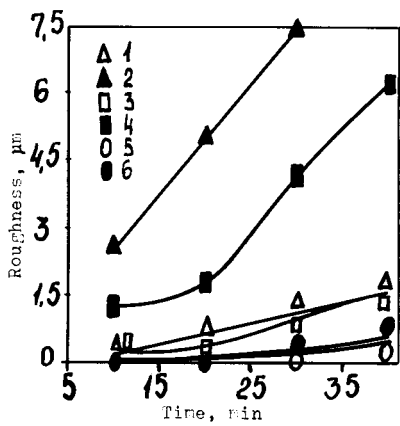


Fig.2 Surface roughness height parameters and thicknesses of coatings on aluminum substrate as functions of time when coating from direct and separated jets of vacuum-arc Ti-N₂ plasma. 1 - thickness of cathode-arc coatings with droplets separation, 2 - thickness of coatings without separation, 3 - R_a for coatings deposited without separation, 4 - R_a for coatings deposited without separation, 5 - R_a for coatings deposited with separation, 6 - R_a for coatings deposited with separation.

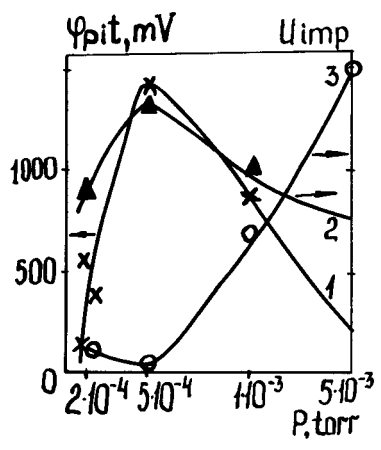
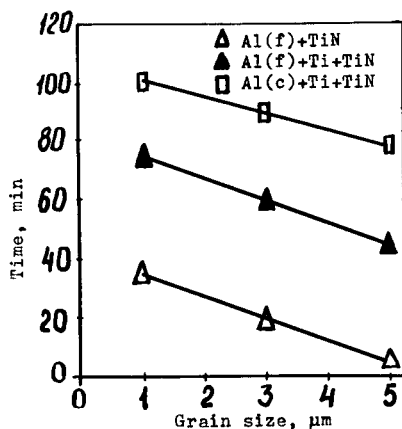
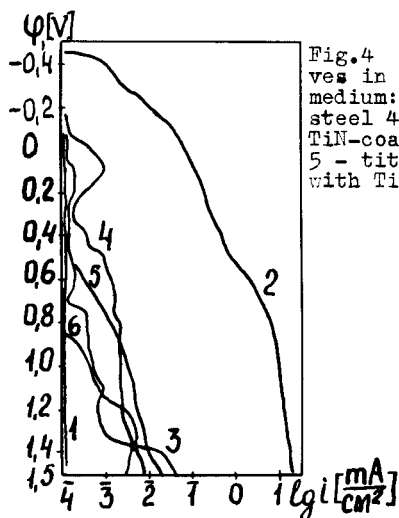


Fig.3 The effect of nitrogen pressure in the process of TiN-coating deposition on (1) pitting-formation, (2) nitrogen concentration and (3) copper concentration in TiN-coatings on copper web.



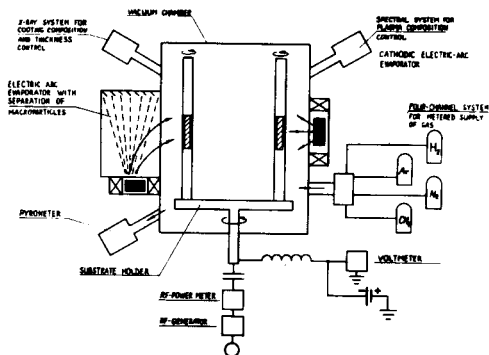


Fig. 1. Block schematic diagram of the installation for the deposition of vacuum-plasma coatings.

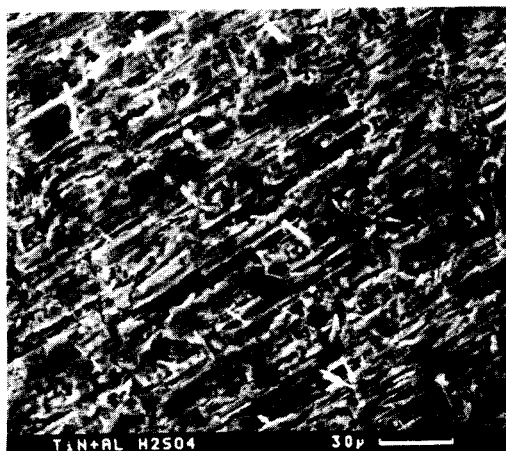


Fig. 5. The Al-web surface with TiN-coating after 200 hours exposure to 0.1 mol/l water solution of H₂SO₄.

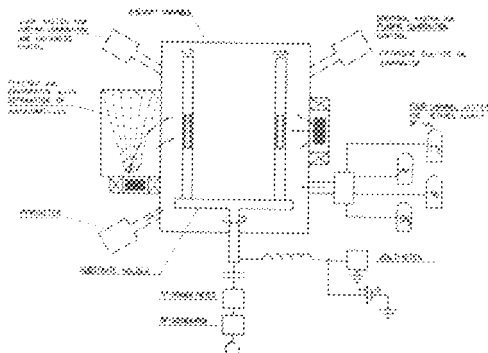


Fig. 1. Block schematic diagram of the installation for the deposition of vacuum-plasma coatings.

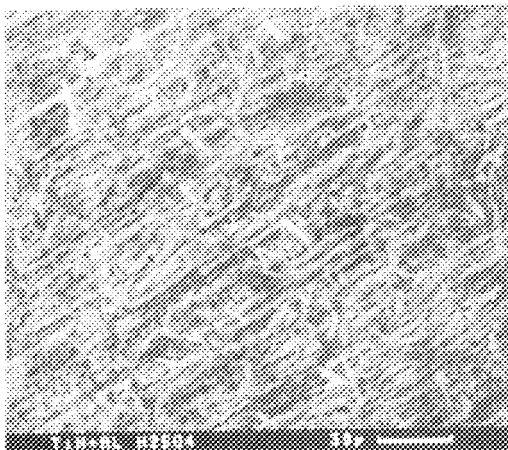


Fig. 5. The Al-rod surface with TiN-coating after 200 hours exposure to 0.1 mol/l water solution of H_2SO_4 .

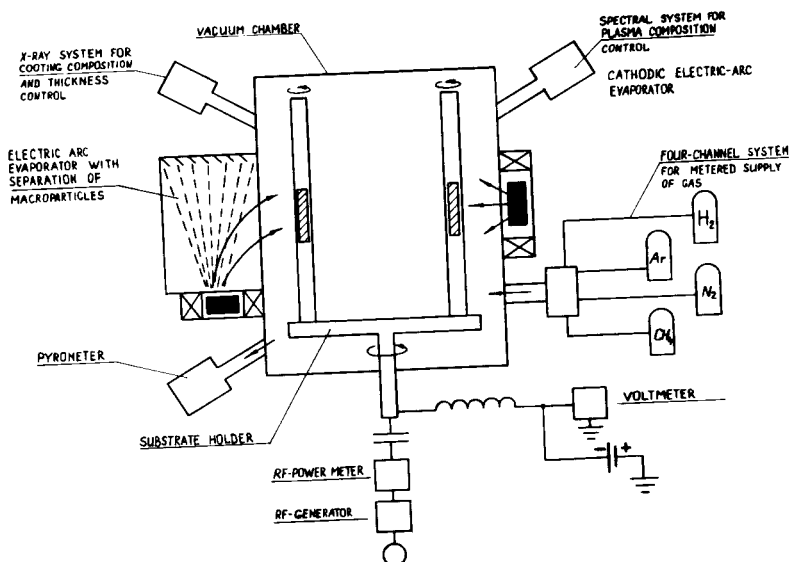


Fig. 1. Block schematic diagram of the installation for the deposition of vacuum-plasma coatings.

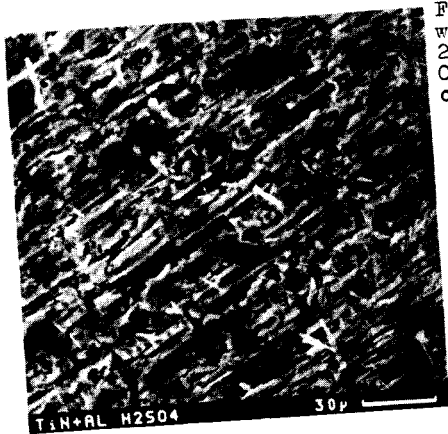


Fig. 5. The Al-web surface with TiN-coating after 200 hours exposure to 0.1 mol/l water solution of H₂SO₄.

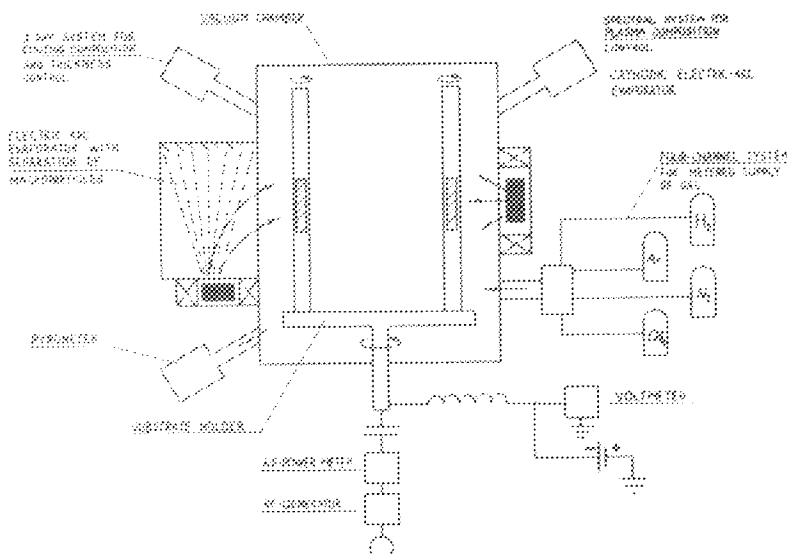


Fig. 1. Block schematic diagram of the installation for the deposition of vacuum-plasma coatings.

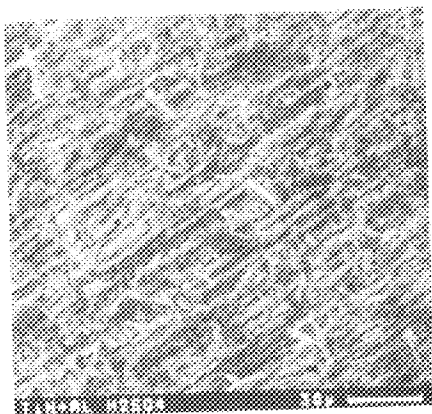


Fig. 2. The Al-7023 surface with TiN-coating after 200 hours exposure to 0.1 mol/l water solution of H_2SO_4 .