UDC 620.197; 533.5:001.89

The specifics of copper coatings production by pulsed arc method

A.M. Zhukeshov, A.T. Gabdullina, A.U. Amrenova*, K. Fermahan, K. Serik,
N.N. Ahmetzhanova, Zh.K. Erenbayeva, Zh. Rysbekova

Al-Farabi Kazakh National University, IETP,al-Farabi 71, 050040 Almaty, Kazakhstan
**e-mail: amrenova_assem@mail.ru*

Nowadayspulsed plasma processing systems are rapidly developing which is expected to achieve more effective results. This paper shows the results of studies ofplasma flows effects generated in VAA-1 vacuum-arc accelerator. Material is treateddue to thermo-physical processes associated with emission of cathode material. The paper presents the results of experiments on coatings obtaining from copper using pulsed vacuum-arc method on a substrate of structural materials such as carbon steel, tool steel, and aluminum.

Key words: vacuum-arc accelerator, spraying, plasma flows, coatings.
PACS numbers: 81.15.-z, 52.80.Mg.

1 Introduction

Among various methods of vacuum plasma surface modification magnetron and arc treatment can be considered as the most studied technologies [1]. However, they have several disadvantages: small processing area, considerable current consumption, heating of cathodes, etc. The use of pulsed systems can improve the results of plasma surface treatment of construction materials [2]. This method of treatment is based on the rapid impact of energy of plasma flows on the surface layers of material. [3] At the same time due to electrode erosion in a certain installation mode, plasma is generated corresponding to the composition of electrode material. It allows the use of this process for metal deposition on different materials.

2 Experiment technique

The paper presents results of experiments conducted at VAA-1 vacuum-arc accelerator. The installation is designed on the basis of pulsed plasma accelerator laboratory of Plasma Department of Institute of Experimental and Theoretical Physics [4]. Plasma flows of VAA are not dispersed along the electrode length, but constricted at cathode surface and released into the inter-electrode space by its own magnetic field. In other words, plasma is formed in VDU as a flow with radially symmetrical distribution of current and appeared to be a fountain pinch.

This plasma processing method allows the application of thin coatings (films) from all conductive materials including refractory metals and carbon [5]. High vacuum is not only prevents particles oxidation, but also reduces the amount of impurities in them due to particles degassing when migration from source to substrate.The use of composite cathodes makes it possible to form films of multi-component compositions with the needed ratio of components. On the other hand, ions of various metals can enter into active chemical interaction with working gases, which are specially introduced into chamber. This allows obtaining the oxide, nitride, carbide and other coatings [6].

Installation view is shown in Figure 1 [4]. Structural units include the vacuum processing chamber for coating applying and all the necessary systems ofprocess – cooling, inlet of working gas, inlet of atmosphere and others. There is a control panel for power supply, monitoring and control systems. The installation design enables to apply different coatings on a variety of bases, from the plane substrates to the cutting tools of complicated form.

Pumping and inlet of gas were conducted in the following sequence: at the beginning, air was pumped out from working chamber to a residual pressure of 1.33×10^{-3} Pa (1×10^{-5} mmHg), and then inlet of working gas was done – argon or nitrogen. After gas inlet the additional pumping out of vacuum chamber to 1.33×10^{-3} Pa was carried out, then the power of arc evaporation mode is turn on, and the mode of arc burn is set. Vaporizer is based on erosive destruction of cathode surface layer made from vaporizable material, under the action of electric arc burning, arising in the discharge gap between cathode and anode.

Figure 1– View of technological installation VAA-1

The arc ignition is provided by passing the ignition pulse with amplitude of about 10 kV. Under current influence film on cathode is vaporized and ionized in ignition area.

Stable burning of vacuum arc is supported by erosion evaporation of cathode material. The arc in water-cooled («cool») cathode is represented as a series of cathode spots with a diameter up to several microns, moving on its end surface with a velocity of about 10^2 m/s. It allows the cathode to be generally cool despite the high energy density concentrated in spot.Each spot includes simulating portion of cathode, region of potential drop, where the positive space charge is focused, and glowing part is an ionization region.

The design of installation provides both continuous and pulsed mode for arc burning. In the latter case – frequencies are in the range of 0.5÷100 Hz. The stability of VAA-1 in experiment is ensured by maintaining anode voltage above 50 V with operating arc currents 40÷120 A, and vacuum of 2×10^{-3}Torr. Pumping out time is 40 minutes. The load current of evaporator is regulated by stages from 5 to 75 A at a voltage of arc not less than 20 V. The current density in cathode spots reaches values of 10^6-10^7 A/cm^2, and the energy density – 10^5-10^8 W/cm^2.

3 Results analysis

This stage includes the experiments which were carried out on optimization modes of metallic coatings deposition from copper and aluminum on substrate material. Therefore, such elements were used as the cathode. Furthermore, it was necessary to consider the type of chemical bonding of coating material to reach its good adhesion to substrate[7]. Samples of substrate were placed on holder at a distance of 10 cm from the end of the inner electrode. The substrate samples were used aluminum, carbon steel and tool steel with dimensions of 1.5×1.5×0.2 cm. It is the most commonly used construction materials in production and changes in physical and mechanical characteristics of surface by applying protective and solid coating can significantly enhance their practical relevance and increase service life.

Scanning electron microscopy (SEM on the Quanta 200i 3D), X-ray diffraction analysis (XRD on Pegasus 2000), metallographic methods were used to analyze the structure and topology of coating.

Technological experiments of VAA-1 at a preliminary stage showed [4] that structure of coatings is strongly dependent on the vacuum level. High-quality coatings on samples were obtained at low discharge currents. At higher currents in VAA-1the formation of dust was observed, so that the cathode is heated to a temperature above 100^0C. However, more recent experiments with cathode forced cooling allow to prevent it from heating. The special features of this technology include the fact that for copper films optimum pressure of working gas in chamber turned out to be 2×10^{-3}-7×10^{-4} mbar. At a higher pressure glow discharge is formed in chamber, and at a lower ones dust is produced. These results indicate that VAA can be successfully used for obtaining nanopowders at high discharge currents [7].

The topology of aluminum sample surface obtained in a scanning electron microscope showed that the copper coating distributed sufficiently uniform over the entire surface of substrate. It has good continuity and adhesion. Formation of spherical structures onselected sites is observed, resulting from curing of precipitated micro-particles after treatment VAA in chamber (Fig 2). This is confirmed by X-ray analysis, which showed that the copper content of nearly 20% relative to ~70% of aluminum (Figure 3).

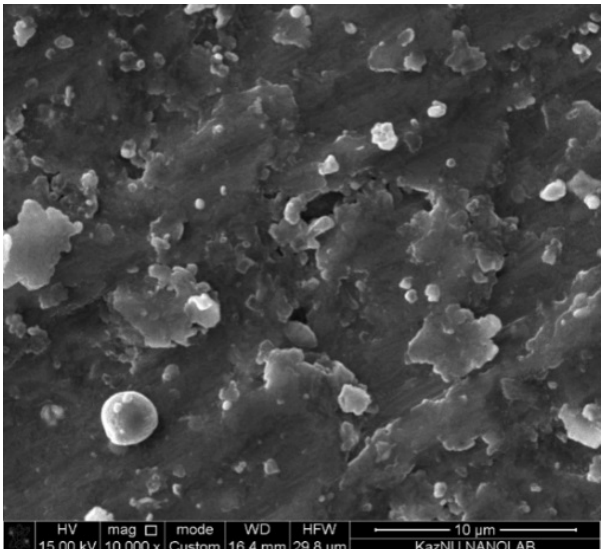

Figure 2 – The microstructure of surface of copper coating on aluminum substrate obtained by SEM (Sample №5)

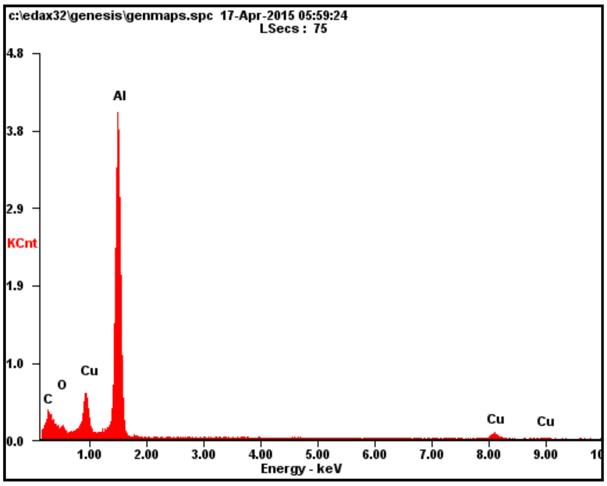

Figure 3 – XRD results of aluminum samplet reated at VAA-1

Experiments results with tool steel also showed the presence of a continuous copper coating formed with a relative copper content up to ~40% and a significant change in base metals content (Fe with 80% to ~44, Cr – from 16% to 10, Mn), which should be associated with significant structural changes in surface layer.

Element	Wt%	At%
CK	3.64	8.37
OK	6.72	11.60
AlK	69.66	71.34
CuK	19.98	8.69
Matrix	Correction	ZAF

The processing mode can be optimized in the case of carbon steel as a substrate. There is a possibility of forming copper coating on carbon steel surface with a very good continuity (copper content up to 67%). The coating is formed in a form of large drops, surface smoothes (Figure 4).

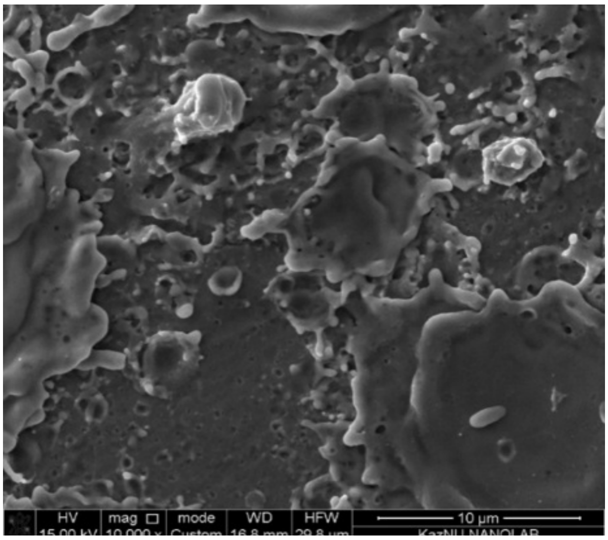

Figure4 – Surface of carbon steel sample

Micro hardness measurements were obtained using micro hardness of HVS-100 type and the most significant changes were found on tool steel surface, observed on the entire surface of investigated area. The increase in micro hardness of the whole surface is a factor of 2, but there are areas with increasing micro hardness up to 3-5 times. However, the measurement of micro hardness of carbon steel and aluminum surface showed no significant changes.

4 Conclusion

Due to experimental results we can conclude that in the case of using vacuum-arc method cathode material is not important, but its size and position relative to its ignitor matters. Furthermore, copper coatings with good continuity (copper content at the surface of carbon steel up to 67%, tool steel up to ~40% of the total value) and adhesion were obtained, when processing in continuous mode for 40 minutes at a frequency of 5 Hz, working voltage of 360 V and at a distance of 10 cm from the end of internal electrode. The possibility of using VAA for obtaining nanopowders by vacuum arc deposition was shown. The most significant changes in micro hardness observed on the entire surface of material were found on surface of tool steel.

Acknowledgements.

The work is funded by grant №3058 GF-4/2015 for basic research in the natural sciences of the MES RK Science Committee.

References

[1] M.A. Lieberman, A.G. Lichtenberg. Principles of plasma discharges and materials processing. – New York: John Wiley & Sons Inc, 1994. – P. 450.

[2] J. Piekoszewski. et.al. Present status and future of pulsed plasma processing of materials in SINS // Nucleonica. – 2000. – № 45 (3). – P. 193-197.

[3] V.I. Tereshin. at al. Pulsed plasma accelerators of different gas ions for surface modification // Rev. Sci. Instrum. – 2002. – Vol. 73. – P. 1-3.

[4] A.T. Gabdullina, A.M. Zhukeshov. Razrabotka sistem upravlenija i kontrolja dlja perspektivnyh vakuumnyh tehnologicheskih ustanovok: otcheto NIR (promezhutochnyj) – Almaty: KAZINTI,– GR № 0112RK02733, Inv .№ 0212RK01417. – 2012. – P. 40.

[5] V.V. Chebotarev, I.E. Garkusha, J. Langner. Surface structure changes induced by pulsed plasma streams processing // J. Problems of atomic science and technology. – Series: Plasma physics. – 1999. – Vol. 3. – P.273-275.

[6] B.A. Vershok, A.B. Dormashev, I.Ja. Margulev. at al. Poluchenie nanoporoshkavakuumnym impul'sno-dugovym metodom // Voprosy atomnoj nauki i tehniki. Ser.: Termojadernyj sintez. – 2006. – Vol. 2. – P. 31–40.

[7] K. Tsuruta, K. Sekiya, G. Watanabe. Velocities of Copper and Silver Ions Generated from an Impulse Vacuum Arc // IEE transactions on plasma sciences. – 1997. – Vol. 25. – P. 603-608.