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Application of vacuum arc deposition surface structural materials

Abstract. This paper presents experimental results of plasma flow impact on the surface of various materials. Using pulsed plasma generated by vacuum arc accelerator, managed to get a copper protective coating on the surface of materials, such as tool steel, carbon steel and aluminum. Treatment of test materials was carried out at various modes of plasma exposure. To demonstrate the deposition process, the paper presents the virtual model of the physical laboratory simulating the creation of the coating. This model allows analyzing this process, to control every stage of the plasma treatment and forms the basis for automation of the proposed deposition technique.
Key words: vacuum-arc accelerator, plasma spraying, protective coating, Virtual Physics Laboratory, Unity 3D.

Introduction

At present, the application of a protective layer on metal surface is one of the effective technological methods to improve the reliability of metal parts industrial equipment. The variety of available materials-coatings gives the possibility to change the properties of the surface layer of every detail depending on the purpose and destination. The use of structural materials is limited by their requirements and high cost. The protective coating on the surface with thickness of a few micrometers may solve the problem. Protective coatings are most commonly used in anticorrosion practice to isolate the metal from corrosive environment, but the coating must be continuous and have good adhesion with the base metal, be impervious to corrosive environment, evenly distributed over the surface, have a high wear resistance, heat resistance and hardness [1-3].

Among the material processing technologies in order to improve the physical and mechanical characteristics of the material is increasingly used plasma treatment of metals, in particular vacuum-arc deposition, which carried out the heating of details and materials to low temperatures (below the melting point of them). The essence of the method is that at certain geometry of electrodes and specific features of applied method is possible to be heated narrow zone of the processed material, which can lead to a local change of the coating structure and properties.

Experiment details

In this paper, experiments on the plasma spraying were conducted on experimental installation VDU-1 [4]. Pulsed discharge in VDU-1 (Fig. 1) occurs between the anode and cathode, arranged coaxially at a distance of 5 cm from each other. The voltage of the ignition is 360÷380 V, anode voltage varies between 120÷130V. Discharge with a frequency of 5 Hz is performed upon reaching a pressure of $44 \div 1{,}6 \times 10^{-4}$millibar for 30÷45 min.

a)

b)

a) Front view; b) Side view

Figure 1 – Vacuum-arc accelerator (VDU-1)

High vacuum not only prevents oxidation of the particles of the applied substances, but also reduces the amount of contaminants in them due to their degassing during the flight from the source to the substrate. The use of compound cathodes allows preparing films of multi-component compositions, e.g., solid solutions of metals with the required ratio of components. On the other hand, ions of various metals can enter into active chemical interaction with working gases, specially introduced into the working chamber and this makes it possible to obtain an oxide, nitride, carbide, and other coatings. This paper presents the results of research on the production of coatings on surfaces of different materials, as samples used aluminum and carbon steel. The samples of the test material were loaded into the working chamber at a residual air pressure $1{,}33\times10^{-3}$Pa (1×10^{-5}Torr). After the gas inflow, electric arc evaporator is powered and sets the arc mode. The ignition of the arc discharge is ensured by transmission of the ignition pulse. The film on the cathode under the current action is evaporated and ionized in the area of ignition Operation of the evaporator based on the erosive destruction of the surface layer of the cathode that provides stable combustion of a vacuum-arc discharge between the cathode and the anode. The treatment time is 40 min, the cathode is copper.

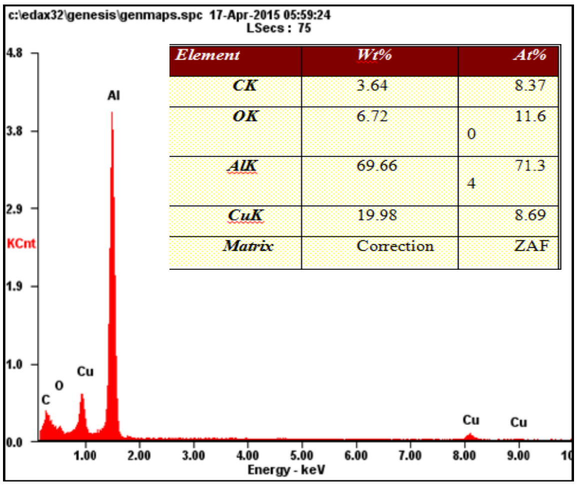
Experimental data analysis

For the analysis of experimental data were applied methods of X-ray analysis (Pegasus 2000), electron microscopy (using scanning electron microscope Quanta 3D 200i and polarizing microscope Axio ScopeA1) and metallography (Vickers, Metaval, HVS-1000).

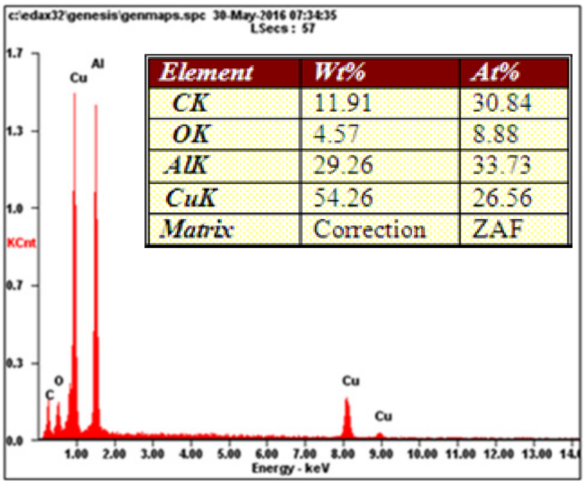
Figures 2 (a and b) shows the data of X-ray analysis of the surface of aluminum samples after processing on the VDU-1 at various parameters. The results of the experiment showed the presence of copper in elemental composition of the surface layer of the samples. In further experiments, were determined operationmodes of VDU-1, at which it was possible to increase copper content from 19.98 to 54.26 % (Fig. 2 b).

X-ray spectral analysis shows that the coating on the carbon steel surface protective layer is also had a positive effect, since the percentage of copper has reached 52,72%, while the iron content fell from 98,47% to 45,50%,which may be associated with structural changes. Along with this, the carbon content decreased from 1,53% to 1,05%, and the oxygen set at 0,73%.

In addition to x-ray analysis, the structure of the carbon steel samples were investigated using a polarizing microscope Axio Scope A1, in which it was found that the surface of the tool steel sample coated with copper protective coating, at least, there are three phase transition. The study of surface topography by electron microscopy showed that plasma treatment leads to surface smoothing, which is typical for aluminum, and carbon steel (Fig. 3-4).



a)

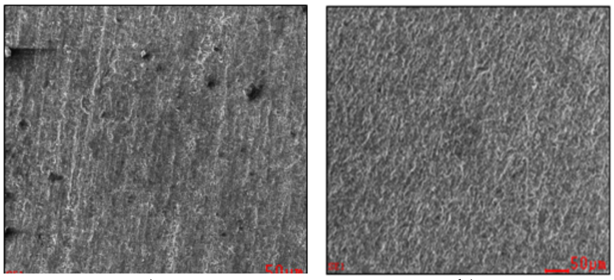


b)

Metallographic investigations of carbon steel samples surface after processing on VDU-1 showed an increase of microhardness at average up 125.57 $H_v$to 148.80H_v.

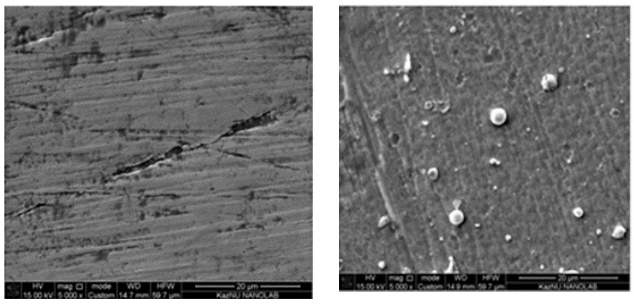
Virtual physics laboratory

For each material it is difficult to find the optimal mode of the plasma processing, therefore, in this paper, was proposed a model for virtual physical laboratory, imitating the process of deposition, which was created in Unity 3D format [5]. This model allows analyzing and controlling every stage of plasma treatment and forms the basis for automation of the proposed deposition technique. The virtual physics laboratory «Studying the plasma spraying» was developed by International Information Technology University, the Computer Engineering and telecommunication department and Al-Farabi Kazakh National University, Physical and Technical Department.



a) b)

Figure 3 – Surface topography of the aluminum samples before (a) and after (b) treatment on VDU-1



a) b)

a) the initial sample of carbon steel (×5000);
б) the structure of the carbon steel sample after coating surface by protective coating (×5000)

Figure 4 – Microstructure of the carbon steel sample

The developed virtual laboratory contains instructions and guidelines on conducting the experiment [6]. It includes the aim of the laboratory work, theory, the experiment equipment, a procedure of the experiment, a report. The experiment methodology is described in detail and the guidelines for the processing of the results are given.

Screenshot of the developed Virtual Physics Laboratory is presented on the Figure 5.

Figure 5 – Screenshot of the Virtual Physics Laboratory «Studying the plasma spraying»

In the virtual application, the panel of data input and calculation of the studied variables was established. Using it, students can change the course of the experiment, which in turn leads to a more detailed understanding of the essence of the studied laws.

Conclusion

Thus, proposed in this paper the method for surface modification of metallic materials using VDU-1 allows obtaining metallic coatings on substrates of structural steels and aluminum alloys with high performance characteristics and requires a small cost of production. The change in the internal structure and properties of the surface during plasma treatment were investigated by x-ray spectral analysis and electron microscopy was showed the presence of copper in all samples of steel and aluminum, there is also significant changes in percentage content of the main elements that may be associated with structural rearrangements in the surface layer after application of the protective coating and phase transitions.

The article discusses the successful example of the development of a virtual laboratory work in physics as part of such a laboratory application.

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