Constructive-technological peculiarities of the machinery for implementing the technology of the surface modification by high-entropic materials with SME under the conditions of high-voltage pulse electromechanical influences

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Abstract. The paper shows the reasonability of using high-entropic materials for a number of multifunctional technical applications on the basis of analysis, systematization and generalization of the market’s demands for operating the machine building products by composition construction of the surface layers using TEPT materials. For the implementation of the technology of surface layers formation from high-entropic materials with SME a multifunctional technological complex was designed and manufactured to develop the technology of surface modification by high-entropic materials with SME under the conditions of high-voltage pulse electromechanical influences.

1. Introduction

During last fifteen years high-entropic alloys (HEAs) attract special attention of material scientists and the whole engineering community as the research into these alloys revealed their attractive properties, such as high solidity and durability, high fatigue resistance and fracture strength, resistance to high-temperature oxidation, high corrosion resistance, and unique electric and magnetic properties. All these properties allow considering the materials as functional structurally sensitive ones. Due to high cost of HEAs because of expensive elements (such as Nb, W, Cr, V, Ni, Ti and Co) inclusion into their composition, films and coatings of high-performance HEAs on the inexpensive metallic bases arouse a great interest [1]. Different technologies are used for obtaining high-entropic coatings: magnetron [2], laser [3], plasma [4], gas-thermal [5]. The most needed methods are high-speed methods: high-velocity oxygen fuel (HVOF) [6] which is, essentially, a combined method of processing, comprising spraying and intensive plastic deformation, which provides the increase of adhesion strength.

The recent researches have shown that among a great variety of HEAs a special place is occupied by less-studied HEAs with thermoelastic phase transformations (TEPT) and materials with shape memory effect (SME) [7]. The peculiarity of these alloys consists in the ability to reveal structural-adaptive properties during the operation activity under definite conditions. The use of materials with TEPT expands the capabilities of the surface modification in increasing durability and survivability of the product. Materials with TEPT can be incorporated into composites, including hybrid ones, in different forms: layers, wires, fibers, and powder inclusions. The efficiency of their usage in
composite materials consists in their ability to absorb the energy of the force influence via superelastic deformation or recovery stress, decreasing the impact of the influence on the composite structure.

Analysis, systematization and generalization of the market’s demands for operating the machine building products by composition construction of the surface layers, using materials with TEPT, have shown that the alloys with shape memory are mostly used in engineering supplements, such as deep-water drives, valves, underwater installations, connectors, packings, self-tightening fastening details and sandblast control. The phase transformations property allows materials with SME to withstand erosion stresses, this is important for the minimization of erosion effect, which borehole devices often experience. The superelasticity of the materials with SME provides good energy dissipation, and can overcome different defects and limitations, which usual methods of passive damping face. The unique cryogenic properties of HEAs make them to be of great demand for cryogenic application, such as jackets of rockets, pipelines and equipment with liquid oxygen or nitrogen. The usage sphere of high-entropic compositions with TEPT is expanding for multifunctional application.

The technologies of surface layers and compositions formation from 2, 3 and 4-component materials with TEPT are elaborated (Patents of the Russian Federation № 2502829, 2535432, 2569871, 2563910) and described in details in some works [8-11]. The formation of coatings from materials with SME for high-entropic materials (comprising 5 and more components) causes considerable difficulties [12, 13].

For obtaining a qualitative composition coating from high-entropic materials it is necessary to seek to provide maximum adhesion strength of the coating with the host-material. To research the process of surface modification by high-entropic materials with SME under the conditions of high-voltage pulse electromechanical influences we need a technological complex which meets the following requirements:

- a chamber for improving adhesion strength with a protective atmosphere (to exclude the formation of oxides that decrease the possibility of thermoelastic phase transformations);
- the possibility to research the improvement of adhesion strength by different methods (by simultaneous surface plastic deformation and high-energy heating by high-voltage pulse);
- universality, the possibility to vary force, electric and electromechanical sources of influence.

2. Materials and methods

Nowadays the use of HEAs as coatings is limited due to insufficient study. Based on the analysis, systematization and experience of the previous researches, we have chosen the compositions on the basis of Ti, Ni, Zr, Hf, Co, Cu for HEAs with TEPT Co_{17.6}Cu_{18.8}Ti_{9.6}Zr_{18.3}Hf_{35.7}, Ni_{17.6}Cu_{18.8}Ti_{9.6}Zr_{18.3}Hf_{35.7}, Ni_{17.8}Co_{17.7}Ti_{8.6}Zr_{18.6}Hf_{36}, Ni_{17.8}Co_{17.7}Ti_{8.6}Zr_{18.6}Hf_{36}. Various structures of the high-entropic compositions were chosen in the way to discover the influence of nickel and cobalt on the structural-phase state and the functional properties of the coatings [14]. All the coatings include Ti, Ni, Zr, Hf, Co, Cu in different combinations, which we have already researched in the compositions of three- and four-component coatings (TiNiCu, TiNiCo, TiNiZr, TiNiHf, TiNiHfCu).

To research the process of surface modification by high-entropic materials with SME under the conditions of high-voltage pulse electromechanical influences we developed a multifunctional technological complex. This complex allows regulating the applied pressure and simultaneous transmitting of high-voltage pulse discharges through HEAs, preliminary having been formed by high-velocity oxygen fuel (HVOF). To conduct this research a high-voltage pulse machinery was designed and manufactured. The machinery has a switched condensing energy storage (100...1400 µF), allowing to form high-voltage discharges with a regulated initial voltage amplitude in the range from 1 to 5 kV.

The registration of current values and pulse width was done by measuring voltage drop on the shunt rating 750 µΩ by the dual-link oscillographLeCroy with the conversion frequency 300 MHz.
3. The constructive-technological peculiarities of the machinery

To carry out the research of the process of surface modification by high-entropic materials with SME under the conditions of high-voltage pulse electromechanical influences a multifunctional technological complex was offered and implemented (see figure 1). It was used for obtaining a qualitative compositional coating from high-entropic materials. The complex consists of a multifunctional vacuum chamber 1, a system of pumping out the air 2, a system of gas supply 3, a high-voltage pulse generator 4.

To preserve the initial coating structure it is necessary to study the impact of the duration of electric pulses thermal influence. To decrease the heating duration a high-speed heating by high-voltage pulse generator is employed. A high-voltage electropulse consolidation is one of the most high-speed methods of obtaining materials and products from electroconductive compositions [15-17].

![Figure 1. A technological complex for developing the process of surface modification by high-entropic materials with SME under the conditions of high-voltage pulse electromechanical influences.](image1)

During the research a multifunctional vacuum chamber was designed and manufactured. It consists of the chamber’s case 1, an observation window 2, a case of bearings 3, fastening shafts of the workpiece 4, a changeable module for electrical and electromechanical source of influence 5, devices for surface plastic deformation 6, and a pressure-and-vacuum gage 7 (figure 2).

![Figure 2. A multifunctional vacuum chamber.](image2)

To research the technology of the surface modification by high-entropic materials with SME under the conditions of high-voltage pulse electromechanical influences a changeable module with electrical vacuum lead-ins for a high-voltage pulse generator is set on the reverse side of the chamber.
scheme of the research of adhesion strength improvement by simultaneous influence of mechanical pressure and high-voltage current pulses is presented in figure 3.

Figure 3. The scheme of the research of adhesion strength improvement by simultaneous influence of mechanical pressure and current high-voltage pulses.

Under the influence of high-voltage pulse the main thermal energy release occurs on the contact of the host-material with the coating. The temperature of the interparticle contacts in the process of current pulse influence may reach the value up to the one corresponding to the condition of the electrical thermal explosion of the interparticle contact [15]. The average temperature in the host-material volume during the high-voltage current pulse influence is considerably lower than the temperature between the host-material and the coating, this is conditioned by the presence of heightened resistance on their interface. The peculiarities of the thermal processes, going on in the material, cause the necessity of the force influence on the workpiece with the coating.

In the developed machinery the condensing storage C is charged by a high-voltage constant current source up to the required voltage through the current-limiting charging resistance $R_{ch}$. The discharge of the condensers occurs with the help of a commutating device on the load resistance $R_L$, which in itself is HEAs, preliminary formed by HVOF on the host-material. For the emergency system of the condensing storage discharge the possibility of connecting discharge resistance $R_{dis}$ is foreseen. In the circuit of the condensing storage discharge shunt $R_{sh}$ is also placed, on which the voltage drop is measured by the oscillograph.

Figure 4. The scheme of the high-voltage pulse machinery.
Figure 5. The scheme and construction of the current-limiting charging resistance.

Figure 6. The construction of the condensing storage.

The time of the thermal energy lead-in into the coating and the host-material is determined by the duration of the high-voltage current pulse. Figure 7 presents the current pulse amplitudes and the time of the high-voltage when influencing HEAs, preliminary formed by HVOF, in different modes of the condensers’ storage charge of the high-voltage pulse generator.

Figure 7. Registration of the current values and pulse width.
4. Conclusions
Based on the received results, we may conclude that for obtaining high operational characteristics of the coatings during surface modification by high-entropic materials with SME under the conditions of high-voltage pulse electromechanical influences it is necessary to identify optimum values of the process’ technological parameters (the amplitude and the duration of current pulses and mechanical pressure, influencing the coating).

The construction has been designed and the technological complex has been manufactured to develop the process of the surface modification. The use of the multifunctional vacuum chamber together with the sources of power and loading system allows flexible modifying of different variants of electromechanical influence upon the workpieces with the applied compositional high-entropic coatings with SME.

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